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**REVISION 1**

NAVAL SHIPS' TECHNICAL MANUAL

CHAPTER 504

# PRESSURE, TEMPERATURE AND OTHER MECHANICAL AND ELECTROMECHANICAL MEASURING INSTRUMENTS

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# CHAPTER 504

# PRESSURE, TEMPERATURE AND OTHER MECHANICAL AND ELECTROMECHANICAL MEASURING INSTRUMENTS

## SECTION 1.

## INTRODUCTION

### 504-1.1 GENERAL

504-1.1.1 This section provides general information concerning portable and permanently installed mechanical and electromechanical measuring equipment/instrumentation usually found in propulsion, auxiliary, and machinery system spaces of naval ships. Information on specific instruments such as pressure calibrators, temperature calibrators, viscometers, flashpoint testers, and hydrometers is included in the sections covering the system or application with which the instruments are customarily associated. In addition, **NSTM Chapter 491, Electrical Measuring and Test Instruments** , covers electrical test instruments. Separate programs govern portable measurement and installed measurement equipment.

### 504-1.2 NAVY CALIBRATION PROGRAM

504-1.2.1 GENERAL. The Navy has established programs to ensure that portable measuring equipment and installed instrumentation is accurate and that the accuracy is traceable to the National Institute of Standards and Technology, (**NIST** ). To operating personnel, this means that all portable and installed measuring instruments used for quantitative readings must be calibrated with standards, which are more accurate. The standard's calibration must be traceable to the **NIST** through an unbroken chain of records. All calibration standards and portable measuring equipment must have an approved label indicating the date and place of calibration before it can be used.

### 504-1.3 DEFINITIONS

504-1.3.1 GENERAL. Accuracy is defined as the degree of correctness with which a measured value agrees with the true or nominal value.

504-1.3.2 CALIBRATION. Calibration is the comparison of a system or instrument of unverified measurement accuracy to a measurement instrument of known and greater accuracy, to detect and correct any variation from established or required performance specifications.

504-1.3.3 FIELD CALIBRATION ACTIVITY (FCA). FCAs are manned by selected ship's force to calibrate the high volume low accuracy installed instrumentation using specific calibrators authorized and certified by NAVSEA. Specifically, the Shipboard Gage Calibration Program (SGCP) FCA on most vessels calibrate pressure or temperature gages and switches. The ship's force operating the SGCP FCA performs ″O″ Level maintenance.

504-1.3.4 INTERMEDIATE MAINTENANCE. Intermediate maintenance is performed by Ship/Shore Intermediate Maintenance Activities (SIMA), or Regional Maintenance Centers (RMC). Intermediate (I) Level maintenance provides detailed troubleshooting/repair of instruments found to be defective by the SGCP FCA and both in-shop and on-site/in place calibration for installed instrumentation beyond the capability of the SGCP FCA authorized phase packages.

504-1.3.5 INSTALLED INSTRUMENTATION (INST2). Installed instrumentation is gages, thermometers, transducers, alarms, and limit switches used to monitor and control the operation of propulsion, auxiliary, and other support systems aboard naval ships.

504-1.3.6 PRECISION. Precision is defined as a measure of consistency or repeatability of the measurements among themselves. (An instrument may be highly precise but not necessarily accurate, whereas a highly accurate instrument is also a very precise one.)

504-1.3.7 SHIPBOARD INSTRUMENTATION AND SYSTEM CALIBRATION (SISCAL). System calibration of the ship's INST2 from sensor to readout is performed by NAVSEA authorized calibration teams.

504-1.3.8 STANDARD. A standard is a device that is used to maintain continuity of value in the units of measurement by periodic comparison with higher echelon or national standards. A standard may be used to calibrate a standard of lesser accuracy or to calibrate test and measurement equipment directly. Calibration standards have a blue label that identifies them as a standard.

504-1.3.9 TRACEABILITY. Traceability is the process by which the value of a measurement is compared, directly or indirectly, through a series of measurements to the value of the national standard or to natural physical constants.

## 504-1.4 SAFETY

504-1.4.1 Requirements for safety are included in each section in this chapter, applicable to the particular instrument involved. The basic purpose of any instrument is to evaluate system operating conditions. If the instrument is not reading correctly, the safe operation of the complete system is jeopardized.

## 504-1.5 PORTABLE MEASURING INSTRUMENTS

504-1.5.1 GENERAL Instruments such as pressure and temperature calibrators, viscometers, flash-point testers, hydrometers, micrometers, torque wrenches and the like are portable measurement instruments.

504-1.5.1.1 Personnel Requirements. The repair, adjustment, and calibration of portable measuring instruments described in this section must be done by personnel specifically trained to perform these duties through successful completion of specific Naval Sea Systems Command (NAVSEA) approved training course(s).

504-1.5.1.2 Calibration and Repair. Calibration intervals for portable measuring instruments are controlled by the **Metrology Requirements List (METRL)** , OD 45845. Organizational (O) level Field Calibration Activities (FCAs) that calibrate electrical/electronic measuring instruments are found on all but the smallest ships. Shipboard Gage Calibration Program (SGCP) FCAs can calibrate electromechanical instruments such as gages, thermometers and torque wrenches within the capability of the authorized phase packages. Portable measuring instruments are calibrated by Intermediate Maintenance Activities (IMAs), Regional Maintenance Centers

(RMCs) or Depot (D) level maintenance activities. These activities perform in accordance with NAVSEA Metrology and Calibration (METCAL) Program directives to provide calibration and corrective maintenance for all portable measuring instruments.

504-1.5.1.2.1 Organizational (O) level maintenance for portable measuring instruments is limited to cleaning of filters, replacement of fuses or light bulbs and refurbishing connectors or adapters. O level parts support is identified on the activity's Consolidated Ships Allowance List (COSAL). Full I & D Level parts support for portable measuring instruments is furnished to the IMAs, RMCs and depots. When replacing portable instruments, form, fit and function are necessary conditions and must be considered for interchangeability with the instrument being replaced. Portable measurement instruments, including calibration standards assigned to the SGCP FCA phase packages, are not authorized to be replaced by ship's force.

## 504-1.6 INSTALLED INSTRUMENTATION (INST2)

504-1.6.1 GENERAL. Installed Instrumentation (INST2) is an integral part of the ships propulsion, power or auxiliary equipment control and monitoring systems. INST2 provides either ″a visual or audible indication of″ or ″a control signal that affects″ the operating status of shipboard systems/equipment.

504-1.6.2 PERSONNEL REQUIREMENTS. The repair, adjustment, and calibration of INST2, as described in this section, must be done by personnel trained to perform these duties through successful completion of specified Naval Sea Systems Command (NAVSEA) approved training course(s).

504-1.6.3 CALIBRATION AND REPAIR. Calibration of INST2 is a maintenance process described in a NAVSEA Technical Manual to verify system/equipment operational status and is performed for:

a. Diagnostic purposes when a parameter monitored by an installed instrument is suspected to be inaccurate.
b. Inspection purposes after an installed instrument is repaired or replaced.

504-1.6.3.1 A NAVSEA Calibration Requirements List (CRL) is a technical manual that documents the configuration of INST2 for each applicable ship class. This CRL should be used for a baseline and customized for each ship in the class. The CRL should list each item of INST2 aboard ship for:

a. Instrument identification
b. Calibration requirement
c. Applicable Calibration Procedure
d. Applicable Calibration Procedure
e. Calibration Interval (periodicity)

504-1.6.3.2 The INST2 CRL technical manual listings are sorted by system, location, and reference number. Included in the listings is a ″CAL″ column containing a (Y) for INST2 requiring periodic calibration or (N) for INST2 not requiring calibration for that specific system/instrument location.

504-1.6.3.2.1 Organizational (O) Level. The calibration of all INST2 pressure and temperature switches or gages should be accomplished on-site in-place by personnel assigned to the Shipboard Gage Calibration Program

(SGCP) Field Calibration Activity (FCA). The SGCP FCA operates the calibration standards specified in Phases B-2, B-5, and D-6 using the applicable calibration procedure to verify instrument accuracy, and identify defective instrumentation in ship operating systems. Applicable calibration procedures are incorporated into one of the following sources, shown in order of precedence:

a. Maintenance Requirements Cards under PMS.

b. System Calibration Procedure Technical Manuals.

c. NAVAIR Instrument Calibration Procedures.

d. System/equipment technical manuals.

504-1.6.3.2.2 The calibration procedure should not be contained in more than one source, and all other documentation should reference that source. Personnel assigned to the FCA to perform calibration shall have successfully completed the NAVSEA approved SGCP FCA operators training course.

## 504-1.7 RED HAND SETTINGS

504-1.7.1 Some pressure gages and thermometers are provided with an adjustable pointer, which is painted red, in addition to the indicating pointer. The red pointer (Red Hand) is supplied as an aid to the operator. For guidance in setting the red pointer, refer to the system technical manual. See paragraph 504-2.3.

## 504-1.8 ORGANIZATIONAL LEVEL MAINTENANCE

504-1.8.1 Organizational (O) level maintenance for INST2 varies by equipment type but includes on-site test and calibration, cleaning, minor adjustment, red hand setting and item replacement. Replacement parts for failed or defective installed instruments are provided as onboard repair parts and identified on the activity's Consolidated Ships Allowance List (COSAL).

## 504-1.9 INSTRUMENT PIPING SYSTEM MAINTENANCE

504-1.9.1 For piping system maintenance requirements refer to **NSTM Chapter 505, Piping Systems** .

## 504-1.10 INSTRUMENT MAINTENANCE

504-1.10.1 GENERAL. Intermediate (I) or Depot (D) level maintenance for INST2 (including on-site calibration) beyond the capability of the SGCP FCA must be system calibrated by a Shipboard Instrumentation and System Calibration (SISCAL) team from an IMA, RMC, or depot activity within the ships geographic location. Repair of control system INST2 is not authorized for O level accomplishment. When INST2 is replaced, the replacement must be identical to or 100% interchangeable with the instrument being replaced. This is accomplished by strict adherence to the three numbering systems (listed in order of preference) used for cataloging purposes as described in the following paragraphs.

504-1.10.1.1 National Stock Number (NSN). The NSN is assigned to identify a stocked item. When required, it is permanently marked on the instrument. Instruments identified with the same NSN are interchangeable for replacement, operation, and maintenance.

504-1.10.1.2 Military Part Number. The military part number consists of alphanumeric symbols representing the basic descriptive characteristics of each instrument in accordance with the applicable specification. Instruments identified with the same military part number are interchangeable for replacement, operation, and maintenance.

504-1.10.1.3 Manufacturer's Part Number. The military part number consists of alphanumeric symbols representing the basic descriptive characteristics of each instrument in accordance with the applicable specification. Instruments identified with the same military part number are interchangeable for replacement, operation, and maintenance.

## SECTION 2.

## PRESSURE MEASUREMENT

### 504-2.1 ENGINEERING PRINCIPLES

504-2.1.1 Pressure is one of the broadest and most complex areas in the field of physical measurements. Its large scope results from the numerous and diversified types of instruments which are used for pressure measurement, while its complexity stems from the many-sided nature of pressure itself. Total pressure is composed of atmospheric and non-atmospheric components.

504-2.1.2 Atmospheric Pressure: Produced by the weight of the atmospheric blanket, atmospheric pressure has a pronounced influence on a great variety of phenomena. It directly influences boiling points, density, and deformation. Correction for atmospheric pressure is required in the physical measurements discussed later in this section.

504-2.1.3 Non-atmospheric Pressure: The second type of pressure, which is artificially produced to transfer or amplify force to produce work. This is the type of pressure that is used in a service station to lift a car, in a machine shop to operate a hydraulic press, or in a turbine to power a propeller or generator. This chapter will deal primarily with liquid or gas pressure and its measurement. Pressure might best be described as force acting over an area. Mathematically the most common equation for pressure is:

$$P = F \text{ (1) } A$$

| | | | |
|---|---|---|---|
| Where: | F | = | the force in units of lbs., newtons, dynes |
| | A | = | the area in units of inch$^2$ , meter$^2$ , centimeter$^2$ |
| And: | P | = | the pressure in units of lbs/in$^2$ , newtons/m$^2$ ,dynes/cm$^2$ |

Sometimes difficulty arises regarding the distinction between force and pressure. This generally can be avoided if the reader remembers that pressure describes a force acting over a particular area. If we restate equation (1) in terms of force we obtain

$$F = PA \text{ (2)}$$

504-2.1.4 The study of fluids at rest is called hydrostatics. Given a fluid in a state of equilibrium under static conditions, the pressure of the fluid against a point on the surface in contact with the fluid is numerically equal to the normal force exerted by the fluid against each unit area of that surface. At any given point within a fluid in hydrostatic equilibrium, the pressure is equal to the sum of the external pressure exerted at the top of the fluid and weight of the fluid in a vertical column of cross-sectional unit area existing over the point. Under static equilibrium conditions of a fluid without flow, the pressures on every point of a horizontal plane in the fluid are equal, and the pressures in any direction about any point are equal. Straight, duplex, differential, compound and vacuum gages are designed for measurement of either a pneumatic or hydraulic pressure medium. Section 3 and Section 4 discuss these various types of gages in further detail.

## 504-2.2 DEFINITIONS

504-2.2.1 PRESSURE. The basic unit of pressure is described as lbs/in$^2$ (psi). There are two types of pressure, absolute and gage. Any pressure that is referenced to true zero pressure is called absolute pressure. Pressure that is measured using the atmospheric pressure for zero reference is called gage pressure. Since most pressures are measured as gage, generally all pressures are considered to be gage, unless otherwise specified. Either the abbreviation ″psi″ or ″psig″ for gage pressure is acceptable. Absolute pressure is always abbreviated as ″psia″.

504-2.2.2 VACUUM. Vacuum is pressure between true or absolute zero and normal atmospheric pressure, which is approximately 14.7 PSI. Vacuum pressure is usually measured in inches or millimeters of mercury (in Hg or mm Hg).

504-2.2.3 DIFFERENTIAL PRESSURE. Differential pressure is the algebraic difference between two pressures measured with respect to a common basis.

504-2.2.4 RANGE. Range is defined as the low and high points within which a continuous indication is obtained.

504-2.2.5 SPAN. The span is defined as the difference between the highest and lowest indications that can be obtained.

504-2.2.6 CONVERSION FACTORS. Conversion Factors. To relate absolute pressure, gage pressure and vacuum, it is necessary to specify the atmospheric pressure that exists at the time and the place of the measurement. Standard atmospheric pressure or barometric pressure (bars) is taken as 14.696 psia, or 760 mm of mercury column at sea level and 0° C (32°F). The most commonly used approximations are 14.7 psig and 29.92 inches of mercury column. During the time and at the place of measurement, the atmospheric pressure may vary considerably from standard pressure. As stated previously, pressure gages indicate the pressure above atmospheric pressure and usually read in pounds per square inch gage (psig). Low-pressure gages may read in inches of mercury (in Hg) or inches of water (in H2O). When converting gage pressure in pounds per square inch (psi) to absolute pressure in the same units of measurement, add 14.7 to the gage reading. An example would be a reading of 50 psig equals 64.7 psia.

504-2.2.6.1 To convert vacuum in inches mercury to absolute pressure in inches of mercury, subtract the vacuum gage reading from the barometric pressure reading. When converting from absolute pressure in inches of mercury to absolute pressure in pounds per square inch, multiply by the conversion factor 0.4912. As an example, for a vacuum of 14 inches of mercury, with barometric pressure of 16. 92 in. Hg., multiplying 16.92 by the conversion factor 0.4912 equals 8.3-psia pressure. Commonly used conversion factors are given in Table 504-2-1.

**Table 504-2-1.** PRESSURE GAGE CONVERSION FACTORS

| Multiply | By | To Obtain |
|---|---|---|
| 1 Atmosphere | 29,9231 | Inches of Mercury |

**Table 504-2-1.** PRESSURE GAGE CONVERSION FACTORS - Continued

| Multiply | By | To Obtain |
|---|---|---|
| 1 Atmosphere | 33.959 | Feet of Water (fresh) |
| 1 Atmosphere | 14.69595 | $Lb/in^2$ |
| 1 Atmosphere | 232.136 | $Oz/in^2$ |
| 1 Atmosphere | 1.01325 | Bars |
| Feet of Water (fresh) | 0.02984 | Bars |
| Feet of Water (fresh) | 0.88109 | Inches of Mercury |
| Feet of Water (fresh) | 0.43275 | $Lb/in^2$ |
| Feet of Water (fresh) | 6.924 | $Oz/in^2$ |
| Inches of Mercury | 0.033864 | Bars |
| Inches of Mercury | 1.135 | Feet of Water (fresh) |
| Inches of Mercury | 0.49115 | $Lb/in^2$ |
| Inches of Mercury | 7.8585 | $Oz/in^2$ |
| Inches of Water (fresh) | 0.0024864 | Bars |
| Inches of Water (fresh) | 0.073424 | Inches of Mercury |
| Inches of Water (fresh) | 0.036063 | $Lb/in^2$ |
| Inches of Water (fresh) | 0.5770 | $Oz/in^2$ |
| Inches of Water (fresh) | 0.9718 | Inches of Water (salt) |
| $Lb/in^2$ | 0.068948 | Bars |
| $Lb/in^2$ | 2.3108 | Feet of Water (fresh) |
| $Lb/in^2$ | 2.0360 | Inches of Mercury |
| $Lb/in^2$ | 16.0 | $Oz/in^2$ |
| $Lb/in^2$ | 2.2457 | Feet of Water (salt) |

Note

1. Inches of mercury (in. Hg) shall indicate inches of mercury referred to 0°C (32°F).
One inch of mercury is equivalent to 0.49115 $lb/in^2$ .
2. Inches of water (in. H20) shall indicate inches of water referred to 20°C (68°F).
One inch of water is equivalent to 0.036063 $lb/in^2$ .

504-2.2.7 READING CORRECTION FOR HEAD OF WATER. On occasion, a pressure gage must be connected below the pipe carrying steam or other fluid. The dead end connection will fill with water or other fluid, and the pressure indicated on the gage is the fluid in the pipe plus the additional pressure created by the weight of the additional fluid or water in the column. When the fluid is steam or fresh water, a subtraction of 0.433 $lb/in^2$ (measured to the center of the gage) will correct the reading to reflect the pressure in the pipe. Similarly, for precise results, the indication of a gage connected above the pipe containing the water should be corrected by adding to the reading 0.433 $lb/in^2$ for each foot of the water column. For example, a gage is connected 10 feet below a pipe carrying steam pressure. The connection line is cool, indicating it is filled with water. The gage reads 250 $lb/in^2$ . Therefore, 250 $lb/in^2$ minus 0. 433 x 10 = 245.67 reflects the actual steam pressure in the pipe.

## 504-2.3 SAFETY

504-2.3.1 RED HAND SETTINGS. On dial pressure gages, the adjustable Red Hand should be set at the maximum normal operating pressure, or at the minimum normal operating pressure of the system or component to which the gage is connected (see **NSTM Chapter 505, Piping Systems** , for pressure definitions). Either the maximum or minimum setting, whichever is most applicable, may be selected. Where specified, if the maximum or minimum operating pressures are not available to watchstanders, the Red Hand should be set at maximum or minimum operating pressure (normal conditions) to provide the watchstanders with this information.

504-2.3.1.1 When the specified maximum and minimum operating pressures are readily available to watchstanders (preprinted on operating logsheets), Red Hand settings slightly beyond these designated pressures should be utilized. In this case, the Red Hand setting should be at a value between the maximum or minimum operating pressure (normal conditions) and the gage indication at which an abnormal condition, for example pump cavitation, is reached, or at which an alarm or protective device such as a pressure switch or pressure relief valve is set.

504-2.3.1.2 The Red Hand setting should be selected so that it is not normally reached during operating and transients, however when the setting is reached, prompt action by the operator will be able to prevent exceeding selected abnormal conditions or protective device settings. Individual Red Hand settings should be documented and retained onboard. In instances where the pressure gage pointer has been offset to compensate for fluid height (see paragraph 504-2.6), the Red Hand shall be similarly offset to reflect actual conditions as cited above. Some examples of Red Hand settings are supplied in Table 504-2-2.

504-2.3.1.3 In certain cases, safe and unsafe conditions are designated on the dial by red and green lines, showing the maximum and minimum pressures, respectively. These lines should be properly labeled at all times.

**Table 504-2-2.** SAMPLE STATIONARY RED HAND SETTINGS

| Gage | Pressures | |
|---|---|---|
| Main Turbine Lube Oil Gage showing Lube OilPressure at the Most Remote BearingMain Steam Inlet Pressure to TurbineDriven Fire Pump | Normal OperatingLow Pressure AlarmRed Hand Setting12 lb/in$^2$ g*13 lb/in$^2$ g**Minimum Normal Operating Pressure515 lb/in$^2$ gRed Hand Setting500 lb/in$^2$ g*515 lb/in$^2$ g** | 13-16 lb/in$^2$ g9 lb/in$^2$ g |
| Main Condenser Vacuum Gage | Normal OperatingLow Vacuum AlarmRed Hand Setting24 in Hg *25 in Hg ** | 25-30 in Hg22 in Hg |
| * 1 Specified Maximum or Minimum pressure readily available to the watchstander.** 2 Specified Maximum or Minimum pressure not readily available to the watchstander. | | |

504-2.3.2 GENERAL GAGE CLEANING. Gages used with gases such as breathing air, oxygen or acetylene shall be kept free from oil or any adhering hydrocarbon. They should normally be cleaned thoroughly in accordance with MIL-STD-1330 and packaged to maintain the clean condition. Other gages shall be cleaned in accordance with the appropriate chapter for the system as when received from the manufacturer. When a gage is known to be contaminated with hydrocarbons, it shall be cleaned or replaced with a new, clean unit.

504-2.3.3 OXYGEN GAGE CLEANING. The Mechanical Instrument Repair and Calibration Shops (MIRCS) on Tenders and Repair Ships include facilities, equipment and trained personnel for cleaning pressure gages from shipboard oxygen gas systems and from other shipboard pressure systems requiring equally stringent cleaning. For example, nitrogen gages used in the purging of the oxygen system or generator must be calibrated only by certified personnel using calibration equipment or standards that have been especially cleaned and allocated to this utilization in accordance with NAVSEAINST 4734.9.

## 504-2.4 PRESSURE INSTRUMENT PIPING

504-2.4.1 PRESSURE INSTRUMENT PIPING. Pressure instrument piping shall be installed in accordance with NAVSEA Dwg 803-1385850 and information given in **NSTM Chapter 505, Piping Systems** .

504-2.4.1.1 Gage Valve and Test Connections. Each pressure instrument is provided with an instrument cutout valve or gage valve accessible to the operator for isolating the instrument should failure occur. A test connection is provided on a test tee or on the combination gage valve and test connection in accordance with MIL-V-24578 for connecting a portable pressure calibrator.

504-2.4.2 CONNECTIONS AND FITTINGS. Several types of gage connectors are currently in use. With pressure, vacuum, and compound gages, the current gage specifications require the use of O-ring unions as detailed in MIL-G-18997 for connection to 1/4 inch OD (outside diameter) tubing. Each gage is furnished with a complete union consisting of the externally threaded end on the gage, the O-ring, the tailpiece, and the union nut.

504-2.4.2.1 Although these connectors are currently specified, gages are furnished with 1/4 inch and 1/2 inch NPT (National Pipe Thread) and flareless (bite type) fittings for the connectors. Consequently, a number of gages currently installed in the fleet have the older connectors and will require slight piping modifications if replacement with the new gages is required.

**CAUTION**

**MIL-STD-777 and MIL-STD-438 currently prohibit NPT fittings above 50 psi.**

504-2.4.3 DEVIATIONS TO CONNECTIONS. Deviations to the connection types identified in paragraph 504-2.4.2 are described in paragraphs 504-2.4.3.1 to 504-2.4.3.9.

504-2.4.3.1 Submarine oxygen storage and transfer piping system pressure gages gave a 6-inch long, 1/4 inch NPS (National Pipe Size) pipe nipple welded to the gage and the gage piping.

504-2.4.3.2 Differential pressure gages as described in Table 504-2-4, as well as other instruments, have internal threaded (female) pressure connections of an O-ring seal type in accordance with MS-16142.

504-2.4.3.3 Three types of instrument to piping threaded adapters are required for connecting pressure instruments having internal threaded connectors. They are as follows:

1. NPT type
2. Flareless (bite type) type
3. O-ring Union type

504-2.4.3.4 Each of the adapters in paragraph 504-2.4.3.3 has one end designed to mate with the internal straight threads of the pressure instrument. The threads of the adapters are in accordance with MS-16142, 1/4-inch OD tubing size (7/16-20 UNF). The opposite end of each adapter is fitted to provide the appropriate piping connection. Internal threaded connectors, when they are required by the component specification, shall be in accordance with the threaded adapter figures in NAVSEA Dwg 803-1385850, and shall have adapters and accessories as applicable for use on differential pressure gages in the unused port of each pressure chamber.

504-2.4.3.5 Metal seals on union type of take down connectors are intended for use on oxygen systems and applications where operating temperatures exceed 149°C (300°F).

504-2.4.3.6 Viton is preferred as seal material except where Buna N or metal seals are required.

504-2.4.3.7 Copper-nickel (70-30) material is used for wetted metal parts of connectors for piping systems and components where nonferrous, corrosion-resistant, weldable material is required.

504-2.4.3.8 Corrosion- resistant steel is intended for wetted parts of connectors for piping systems where ferrous materials suitable for welding or brazing are required.

504-2.4.3.9 Couplings and reducing bushing types (welded or silver brazed) are intended for use as pipe-to-tube adapters in specific piping configurations (see NAVSEA Dwg 803-1385850).

**5042-2.5 PRESSURE SNUBBERS**

504-2.5.1 DEFINITION. A pressure snubber is a pressure transmitting device that restricts the rate of fluid flow to a pressure sensing instrument and, as a result, the rate of pressure change.

504-2.5.2 APPLICABILITY. Pressure snubbers should be used when a gage, transducer, or other pressure sensing instrument is subject to constant and rapid pressure fluctuations or hydraulic shocks which have the potential to damage the pressure sensing element and result in premature failure. In the case of pressure gages, such pressure fluctuations may result in excessive wear to the drive mechanism and rapid pointer oscillation, making reading difficult. A pressure snubber greatly reduces the magnitude of the pressure oscillation and thus prolongs the life of the pressure sensing instrument.

504-2.5.2.1 NAVSEA Standard Drawing 803-1385850, **Piping, Instrument Piping For All Service** specifies that, when required, pressure snubbers shall be installed immediately upstream of the instrument. This drawing also directs that instruments used to provide a signal to a control system in which the signal must be received in 15 seconds or less shall not be equipped with a pressure snubber.

504-2.5.3 CLASSIFICATION. Pressure snubbers are classified in MIL-S-2940 (Snubbers, Fluid Pressure, Instrument Protection) according to their type (service fluid), class (operating pressure), composition (material), end connections, and cleanliness (cleaning requirements). See Table 504-2-3.

**Table 504-2-3.** MIL-S-2940 SNUBBER CLASSIFICATION

| | |
|---|---|
| Type(Service Fluid) | 1- Oils, hydraulic fluid with viscositites above 20 centistokes (cSt)2 - Fresh water, steam gasoline, light oils with viscositites below 20 cSt3 - Gases4 - Seawater |
| Class(Operating Pressure) | L - 10 to 100 lb/in$^2$ gageH - 1001 to 6000 lb/in$^2$ |

**Table 504-2-3.** MIL-S-2940 SNUBBER CLASSIFICATION - Continued

| | |
|---|---|
| Composition (Material) | A - Copper-nickel alloyB - Nickel-copper alloy (monel) (Composition ″B″ is the only material specified for seawter applications.)C - Corrosion resisting steelX - Other |
| End Connection | P - Pressure gage general applicatoinsF - Pressure gage flaareless (bite type) applicationsT - Pressure transducer general applicationsS - Other (connections specified when ordering) |
| Cleaning Requirements | G - General applicationsX - Oxygen an ddry nitrogen applicationsZ - Special Cleaning |

504-2.5.4 DESIGNS. There are a number of snubber designs commercially available; however, the only two designs presently approved for shipboard use per MIL-S-2940 are porous metal and piston.

504-2.5.4.1 A porous metal design snubber is depicted in Figure 504–2–1. It is nonadjustable and consists of a porous metal element, available with different porosities, installed in a pressure fitting. MIL-S-2940 prohibits the use of snubbers containing porous metal elements for gas and seawater applications, and restricts their use to oil and water applications with contaminates less than 25 microns in size.

504-2.5.4.2 A porous metal design snubber is depicted in Figure 504–2–2. It is nonadjustable and consists of a porous metal element, available with different porosities, installed in a pressure fitting. MIL-S-2940 prohibits the use of snubbers containing porous metal elements for gas and seawater applications, and restricts their use to oil and water applications with contaminates less than 25 microns in size.

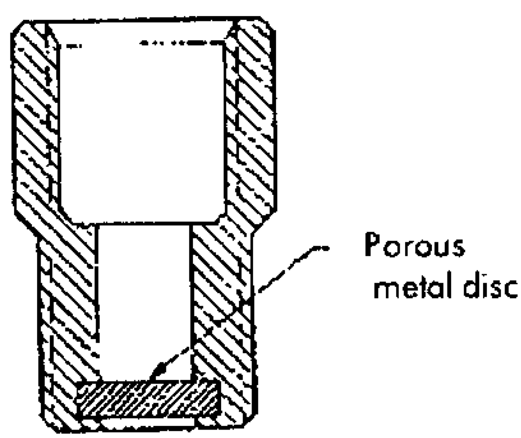


Figure 504-2-1. Porous Metal Disc Pressure Snubber

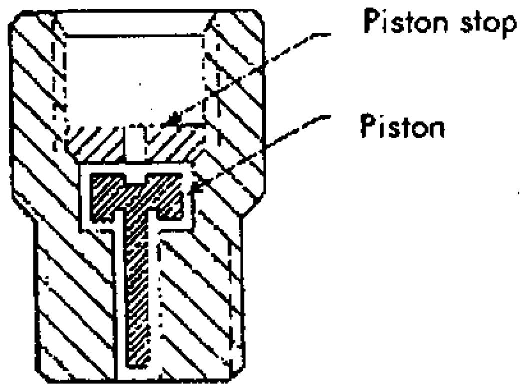


Figure 504-2-2. Piston Type Pressure Snubber

504-2.5.5 SAFETY. As with any pressurized system, safety is of primary concern. In addition to potential hazards associated with working with a pressurized fluid, there are other cautions that must be observed. These include contamination and reuse.

504-2.5.5.1 Contamination. Contamination can occur when fluid from a calibration system (or reuse from a different application) comes in contact with the internal portions of a snubber which is intended for use in an incompatible fluid system, e.g., oil in a gas or water system. The consequences of incompatibility can range from simple contamination resulting in improper snubber action to explosive failure when oil is introduced into an oxygen system.

504-2.5.5.2 Reuse. It is strongly recommended that snubbers not be transferred from one application to another. If snubber transfer is necessary, then transfer from one application to another should only be done after concerns about chemical and material, viscosity, and pressure compatibility are addressed. In general, the same criteria used to select a snubber for a particular application should govern its reapplication.

504-2.5.6 MAINTENANCE. There are several indicators of pressure snubber malfunction. These are minimal or no snubbing action, excessive delay in the response of the pressure sensing instrument, and lack of response of the pressure sensing instrument. Lack of snubbing action may indicate deterioration of either the porous metal element or the piston. Excessive delay or lack of response is symptomatic of the accumulation of particulates either within the porous metal element or around the piston assembly.

504-2.5.6.1 If improper operation traceable to the pressure snubber is indicated, then it should be removed and inspected. If the snubber is of the porous metal design, then it should be replaced - it is not practical to clean or repair it. If the snubber is of the piston design, then it can be disassembled and cleaned. If required, the piston can be replaced. Even if improper snubber operation is not evident, snubbers should be inspected in accordance with existing preventive maintenance procedures.

## 504-2.6 FLUID HEAD CORRECTION

504-2.6.1 GENERAL. Fluid head correction will be required for liquid service gages when the elevation difference between the gage and root connection to the pressure source is equal to or greater than 1 percent of normal operating pressure. Steam service gage lines are kept filled with water; therefore, this height correction must be considered. Table 504-2-4 is used for installation height correction.

504-2.6.1.1 The correction for height differences greater than 12 inches may also be determined from Table 504-2-4. An example is provided in paragraph 504-2.6.1.2.

504-2.6.1.2 Suppose that the height difference between a steam service gage (fresh water) and pipe connection is 6 feet 9 inches. The procedure for obtaining the required corrections is as follows:

1. The correction for 6 feet is 6 times the correction for 1-foot (12 inches).

2. From Table 504-2-4, the correction for 12 inches (fresh water) is 0.433 lb/in$^2$ .

3. The correction for 6 feet is 6 X 0.433 = 2.598 lb/in$^2$ .

4. From Table 504-2-4 the correction for 9 inches (fresh water) is 0.325 lb/in$^2$ .

5. The required correction for 6 feet, 9 inches is the sum of the results obtained in step 3 and step 4; 2.598 + 0.325 = 2.923 lb/in$^2$ .

6. If the gage is below the root connection, the correction is subtracted from the gage reading. If the gage is above the root connection, the correction is added to the gage reading.

**Table 504-2-4.** FLUID HEIGHT CORRECTION FACTORS

| | **Liquid** | | |
|---|---|---|---|
| **Difference in Height (in)** | **Fresh Water** | **Sea Water** | **Oils** |
| 1 | 0.036 | 0.037 | 0.029 |
| 2 | 0.072 | 0.074 | 0.058 |
| 3 | 0.108 | 0.111 | 0.087 |
| 4 | 0.144 | 0.148 | 0.116 |
| 5 | 0.181 | 0.186 | 0.145 |
| 6 | 0.217 | 0.223 | 0.174 |
| 7 | 0.253 | 0.260 | 0.203 |
| 8 | 0.289 | 0.297 | 0.232 |
| 9 | 0.325 | 0.334 | 0.261 |
| 10 | 0.361 | 0.371 | 0.290 |
| 11 | 0.397 | 0.408 | 0.319 |
| 12 | 0.433 | 0.445 | 0.338 |

504-2.6.2 Applicable propulsion plant gages for nuclear powered ships and prototypes (including off-hull systems) shall have the gage pointer adjusted (offset) to compensate for fluid height. Labels shall be affixed on and near each gage that state that the gage pointer has been physically offset to correct for fluid height and cite the positive/negative correction actually applied.

504-2.6.3 With the exception of those gages cited in paragraph 504-2.6.2, fluid height correction shall only be by addition or subtraction to the pressure gage reading. Pointers shall not be adjusted. Labels shall be affixed on and near the gage with the required correction and direction to add or subtract.

## 504-2.7 PRESSURE GAGE CALIBRATION

504-2.7.1 PRESSURE GAGE CALIBRATION. Pressure gages are most often calibrated by adjusting their mechanisms so the pointer gives accurate readings over the range of the gage. The accuracy is determined by testing the range against a standard pressure at several points up to full scale, then rechecking as the pressure is returned to zero. Some recommended practices are:

a. Cycle the gage twice to full scale before testing.

b. Test the gage at 25% increments upscale and 25% increments downscale, including normal operating pressure.

c. The applied pressure should not exceed the test point when testing upscale or down. If it does, return to the previously checked point and continue from there.

d. Test readings should be taken after the gage is lightly tapped near the center of the dial in order to minimize friction errors.

504-2.7.2 CALIBRATION FLUID. Gages calibrated at I or D Level calibration activities may be calibrated only with dry nitrogen, air, or certain liquids that are compatible with the gage service fluids. These precautions are taken to minimize contamination of gages and the systems in which they are to be installed. Some portable calibration equipment used for in-place or on-site calibration will use dry nitrogen, air, distilled water, or oil as the pressurizing means.

504-2.7.3 CLEANING. When a pressure gage is removed from the installed position to undergo corrective maintenance, it must be cleaned in order to prevent contamination of test equipment. The term clean pertains to the internal surfaces of a sensor subassembly, which are exposed to the service fluid of any pressure instrument. Depending on the service fluid use the appropriate degree of cleanliness.

504-2.7.4 MECHANICAL INSTRUMENT REPAIR AND CALIBRATION SHOPS (MIRCS). Tenders and Repair Ships include facilities, equipment and trained personnel for cleaning pressure gages from shipboard oxygen gas systems and from other shipboard pressure systems requiring stringent cleanliness. For example, nitrogen gages used in the purging of the oxygen system or generator must be calibrated only by certified personnel using calibration equipment or standards that have been especially cleaned and dedicated to this purpose in accordance with NAVSEAINST 4855.9.

504-2.7.5 IN PLACE AND ON-SITE GAGE CALIBRATION. On site calibration of oxygen gages shall be performed in accordance with NAVSEA 0987-LP-022-3010. These instructions pertain to other than submarine electrolytic oxygen generators. In place calibration of the submarine electrolytic oxygen generator gages and system piping is covered in applicable MRCs under the Planned Maintenance System (PMS) due to variations of generator and piping configurations. In either situation, calibration of oxygen system gages must prevent contamination and can be performed only by certified personnel using approved calibration standards.

504-2.7.6 FLUID SEPARATORS. Fluid separators are designed to separate system fluids from calibration pressurizing equipment. Fluid separators should always be used when in place or on site calibration is performed and when calibration pressurizing equipment and service pressure equipment are not compatible. A general guide to the type of fluid to be used is contained in Table 504-2-5.

**Table 504-2-5.** FLUIDS USED FOR GAGES

| Gage Service | Calibrated With |
|---|---|
| Air or Nitrogen | Dry Nitrogen or Air |
| Fresh Water or Steam | Dry Nitrogen, Air or Fresh Water |
| Seawater or Oils | Oil Actuated Comparator or Use Selected Fluid Separator with Dry Nitrogen or Air Comparator |

## SECTION 3.

## PRESSURE GAGES

### 504-3.1 ENGINEERING PRINCIPLES

504-3.1.1 PRESSURE GAGES. Pressure gages used in Naval applications are based on either the C-Type Bourdon tube or Direct Drive Bourdon tube technologies. The common principle upon which both are based is the elastic deformation of a metallic tube by an internal pressure. In both cases the deformation is proportional to the pressure applied.

504-3.1.2 C-TYPE PRESSURE GAGES. The C-Type Bourdon tube named for its shape is constructed of a Bourdon tube connected by mechanical linkages and gearing to a pointer. See Figure 504–3–1. The movement of the pointer with respect to a fixed dial indicates pressure changes with graduated markings representing magnitudes of pressure.

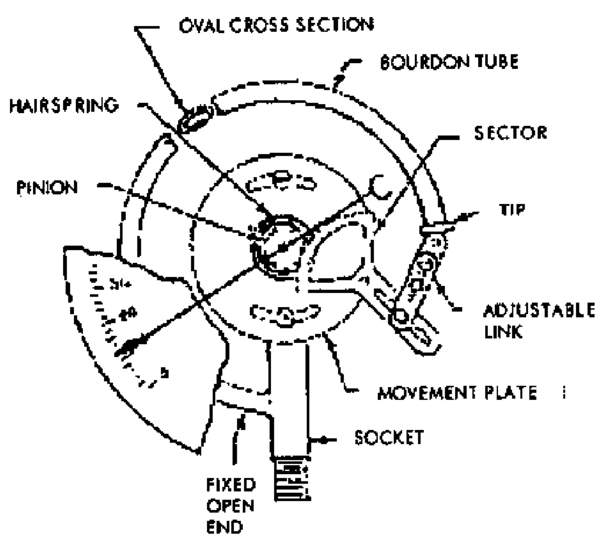


Figure 504-3-1. C-Type Bourdon Tube Pressure Gage

504-3.1.3 DIRECT DRIVE PRESSURE GAGES. Direct Drive pressure gages are constructed of a spiral wound Bourdon tube directly connected to the pointer shaft with no linkages or other moving parts. See Figure 504–3–2. Internal pressure results in an ″uncoiling″ of the Bourdon tube. The uncoiling imparts a twisting motion to the pointer shaft, which rotates the pointer with respect to a fixed dial with graduated markings.

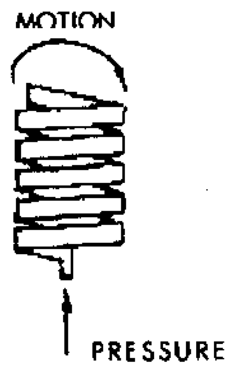


Figure 504-3-2. Direct Drive Bourdon Tube

## 504-3.2 DEFINITIONS

504-3.2.1 PRESSURE. Refer to Section 2 definition, paragraph 504-2.2.1.

504-3.2.2 ABSOLUTE PRESSURE ($P_A$). Absolute pressure is the total pressure exerted by a fluid; it is pressure measured with respect to a perfect vacuum (or zero pressure) datum.

504-3.2.3 ATMOSPHERIC PRESSURE ($P_S$). Atmospheric pressure is the pressure exerted by the weight of the atmosphere at a given point; it is the weight of one square unit column of air extending to the top of the atmosphere. The average atmospheric pressure at sea level is 14.696 pounds per square inch absolute ($lb/in^2$ a). Barometers are used to measure this pressure in inches of mercury (in. Hg) or millibars (Mb) (see Section 8).

504-3.2.4 DIFFERENTIAL PRESSURE ($P_D$). Differential pressure is the algebraic difference between two pressures measured with respect to a common basis (see Section 4).

504-3.2.5 GAGE PRESSURE ($P_G$). Gage Pressure is a special case of differential pressure. Positive gage pressure is the difference between absolute pressure and atmospheric pressure, or $P_G = P_A - P_S$ .

504-3.2.6 VACUUM ($P_V$). Vacuum, as used in this chapter, is a special case of differential pressure known as positive vacuum. Positive vacuum is the difference between atmospheric pressure and absolute pressure, or PV = PS - PA.

504-3.2.7 RANGE. Refer to Section 2 definition, paragraph 504-2.2.4.

504-3.2.8 SPAN. Refer to Section 2 definition, paragraph504-2.2.5.

504-3.2.9 HEMPI. Helical Edgeview Mechanical Pressure Indicator (HEMPI) is as its acronym describes, an edgeview pressure indicator with a vertical scale. It employs the direct drive Bourdon tube technology (see paragraph 504-3.1.3).

## 504-3.3 SAFETY

504-3.3.1 GAGES. Gages to be used with gases (such as air, oxygen or acetylene) shall be kept free from oil or any adhering hydrocarbon. They should be maintained in a clean condition. When a gage used to measure gases is known to have been contaminated by hydrocarbons it shall be cleaned or replaced with a new clean unit.

504-3.3.2 SAFETY CASES. Pressure gages procured to MIL-G-18997 are provided with a means to relieve pressure out of the back of the case should slow leakage or rupture of the pressure sensing subassembly occur. The gage has a solid wall between the gage dial and the bourdon tube for operator protection.

504-3.3.3 RED SET HAND. MIL-SPEC gages are provided with a Red Set Hand for indicating, for example, maximum normal operating pressure (see paragraph 504-2.3).

## 504-3.4 DESCRIPTION

504-3.4.1 PRESSURE, VACUUM, COMPOUND AND DUPLEX GAGES. Pressure, vacuum, compound and duplex gages are used by the Navy to measure the difference between atmospheric pressure and pressure in a pipe or vessel. Typical fluids that are measured include saturated steam, superheated steam, seawater, fresh water, oils, and gases. Compound gages measure both pressure and vacuum about a zero gage pressure point. Duplex gages have two complete pressure sensing elements combined in one case. Each element acts independently and indicates a separate pressure.

504-3.4.1.1 Navy standard pressure gages are manufactured to the basic gage standards specified in Gages - Pressure Indicating Dial Type - Elastic Element, American National Standard Institute (ANSI) B40.1, although additional unique Navy requirements relative to standard configurations, shock, vibration, special connections and cleanliness are superimposed. These requirements are specified in MIL-G-18997 gage, Pressure, Dial Indicating.

504-3.4.2 DUPLEX PRESSURE GAGES. Duplex gages have two complete pressure sensing elements combined in one case. Each element acts independently and indicates a separate pressure. A typical use for these gages is in the engine room to show that the lubricating oil strainers are open. When one element is connected to the strainer inlet and the other to the outlet, a clogged strainer will be indicated by a noticeable pressure difference. Duplex gages are available only in the C-type Bourdon tube design.

504-3.4.3 SUPPRESSED PRESSURE GAGES. A suppressed scale pressure gage has a scale that starts at some point above zero. The span of a suppressed scale gage is the difference between the maximum and minimum scale pressures. For example the span of a 1000/1500-psi gage is 500 psi. Suppressed pressure gages are used on Navy ships for measuring superheated outlet or main steam pressure on 1200 psi boiler plant ships. The suppressed scale gage provides higher resolution and accuracy at the operating pressure.

504-3.4.4 RETARDED PRESSURE GAGES. A retarded scale pressure gage has a scale in which either one or both ends are compressed. The free motion of the Bourdon tube is modified by engagement with a spring in the retarded zone. The span of a retarded gage is the difference between the limits of the nonretarded portion of the scale.

504-3.4.5 CAISSON GAGES. Caisson gages are used on submarines to measure ambient pressure within a compartment such as escape chambers. Caisson gages employ a sealed Bourdon tube, which deflects due to an applied external pressure. The case and mechanism are open to the compartment. The Bourdon tube is sealed at atmospheric pressure.

504-3.4.6 REFRIGERANT GAGES. Refrigerant gages are compound pressure gages used to measure refrigerant pressures. Refrigerant gages are distinguished by a temperature equivalent scale for the applicable refrigerant in addition to the pressure scale on the dial face.

## 504-3.5 OPERATION

504-3.5.1 SELECTION OF PRESSURE GAGES. When selecting a pressure gage, choose one that has a range in which the anticipated maximum normal working pressure is about 66 percent of full scale reading. The system operating conditions are in the middle third of the scale range, and the relief valve setting for the system is equal to or less than the maximum scale reading. Where pressures exceeding the maximum graduations are known to occur, use a gage with a higher range. Gages should not be selected which permit operating conditions to occur in the first five percent of the scale range.

504-3.5.2 SIZE AND MOUNTING. The size of a gage is determined by the nominal diameter of the dial. MIL-G-18997 sizes are 2, 2-1/2, 3-1/2, 4-1/2, and 8-1/2 inch diameters. e.

504-3.5.3 ACCURACY. MIL-G-18997 pressure gages are as follows:

| | |
|---|---|
| 2 inch dials | plus or minus 3% of span |
| 2-1/2 inch dials | plus or minus 2% of span |
| 3-1/2, 4-1/2, 8-1/2 inch dials | plus or minus 1% of span |

504-3.5.4 CLASSIFICATION OF PRESSURE GAGES. Pressure gages built in accordance with MIL-G-18997 are classified in accordance with the following variables:

a. Design

b. Type of Pressure

c. Dial Size and Case Design

d. Elastic Element Material

e. Style

f. Dial Range

g. Color

h. Pressure Connection

i. Connection Location

j. Liquid Fill Case Fluid

k. Vibration Category

l. Cleanliness

504-3.5.4.1 The MIL-G-18997 Classification variables and their corresponding symbols are depicted in Table 504-3-1.

**Table 504-3-1.** MIL-G-18997 CLASSIFICATION VARIABLES

| **Design** | **Symbol** |
|---|---|
| SimplexSimplex - Special Applications Caisson Cruising Range Oxygen RefrigerantDuplex | **S K C X R D** |
| **Type of Pressure** | |
| Gage PressureVacuumCompoundSuppressed, Gage PressureRetarded, Gage PressureRetarded, Compound Pressure | **G V C S R T** |
| **Dial Size and Case Design** | |
| 2 Stem Mounted2-1/2 Stem Mounted3-1/2 Flush/Surface Mounted4-1/2 Flush/Surface Mounted8-1/2 Flush/Surface Mounted1-1/4 Verical Scale (Flush) | **1 2 3 4 8 H** |
| **Elastic Element Material** | |
| K-MonelInconelOptional(K-Monel or Inconel) | **M I N** |
| **Elastic Element Style** | |
| C-type Bourdon TubeHelical Bourdon Tube Gear DriveHelical Bourdon Tube Direct DriveOptional (any of the above) | **C H D N** |
| **Dial Range Gage Pressure Range (psig)** | |
| 0/150/300/600/1000/2000/3000/4000/6000/8000/10000/15000/20000/30000/50000/80000/10000 | **15P 30P 60P 1HP 2HP 3HP 4HP 6HP 8HP 1KP 15HP 2KP 3KP 5KP 8KP 10KP** |
| **Vacuum (in HG)** | |
| 0/30 | **V** |
| **Compound** | |
| 30/0/1530/0/3030/0/6030/0/10030/0/15030/0/20030/0/300 | **15C 30C 60C 1HC 150C 2HC 3HC** |
| **Compound** | |
| 30/0/40030/0/600030/0/80030/0/1000 | **4HC 6HC 8HC 1KC** |
| Note: For Refrigerant Ranges add the appropriate numeral following the letter ″C″ in the compound range symbol listed above. | |
| R11R12R22R114R134A | **1 2 3 4 5** |
| **Suppressed** | |
| 1000/1500 | **S** |
| 0/3030/0/3030/0/150 | **R1 R2 R3** |
| **Caisson (psig and ft of seawater)** | |
| 0/100 and 0/2300/200 and 0/4500/300 and 0/6750/380 and 0/8500/400 and 0/900 | **1HK 2HK 3HK 380K 4HK** |
| **Receiver** | |
| 3/153/270/60 | **15N 27N 60N** |
| **Oxygen Service** | |
| 0/1000/30000/5000 | **1HK 3KX 5KX** |
| **Cruising Range** | |
| 30/0/200 | **T** |
| **Dial Color** | |
| Black Dial, White MarkingsWhite Dial, Black MarkingsSpecialVertical | **B W S G** |
| **Pressure Connection** | |

**Table 504-3-1.** MIL-G-18997 CLASSIFICATION VARIABLES - Continued

| Design | Symbol |
|---|---|
| O-ring1/4 NPT Welded NippleWelded NippleThreaded Vent, caissonFlareless, bit type7/ 17-20 UNF-2B HEMPI | **P R W K C H** |
| **Connection Location** | |
| BackBottom5 o'clock | **A O C** |
| **Land Fill (2 and 2-1/2 inch only)** | |
| NoneSilicone | **N S** |
| **Vibration Category** | |
| Category A Flush/Surface mount pressure gagesCategory B HEMPI gagesCategory C Stem Mount and Liquid Filled gages | **A B C** |
| **Connection Location** | |
| General applicationsOxygen applicatons | **G X** |

An example is expressed below:

SG4NN5KPWRONAG*

* Simplex pressure gage with a 4 1/2 inch dial, optional Bourdon tube style, optional Bourdon tube material, with a range of 5000 psig, white dial with black markings, O-ring union connection, bottom connected, no fill fluid grade A vibration, cleaned for general applications.

504-3.5.5 INSTALLATION OF PRESSURE GAGES. Pressure gages should be mounted on a suitable gage board. The gage board should not be attached to operating machinery or to surfaces subject to vibration. Mount all gages and gage boards so vibration of the gages is minimized. Gages mounted on gage boards must be mounted on truly flat surfaces. Care should be taken to ensure that tightening of the securing bolts does not warp the case.

504-3.5.5.1 Panel gages are designed to be either surface or flush mounted. When flush mounted, a flush mounting ring (in accordance with NAVSEA Drawing 803-841569) is used.

504-3.5.5.2 Procedural steps for installing flush mounted pressure gages in a panel are:

1. Apply ring from front side of panel, so that weld bolts enter panel hole.
2. Working from the front of the panel, place clamping ring (4) on the weld bolts and loosely assemble top spacer post to hold ring (1) in place.
3. From rear of panel, apply the two lower spacer posts, just loose enough to permit rotation of ring in panel.
4. Place a level or straight edge across the two lower spacer posts.
5. Rotate the ring as necessary to bring posts in a horizontal line.
6. Tighten all spacer posts. Ensure that the full surface of the clamping ring is brought to bear against the panel.
7. Refer to for flush mounting details.

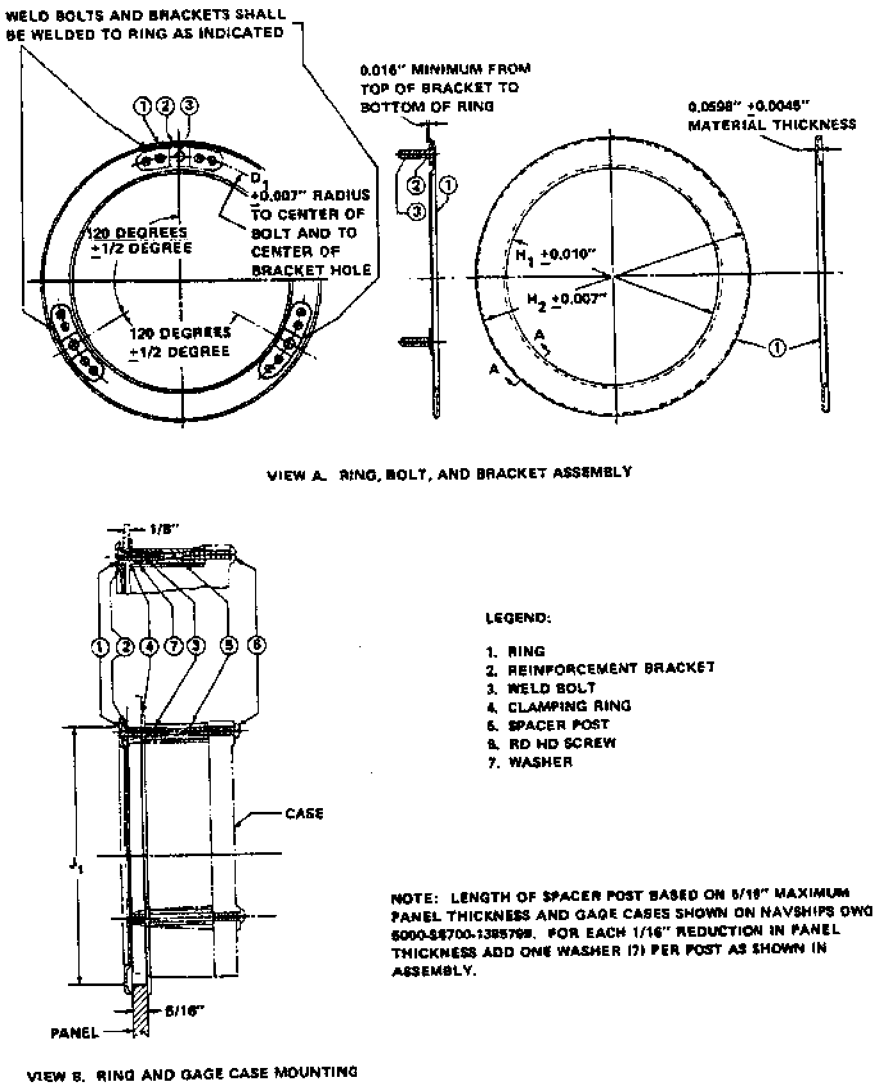


Figure 504-3-3. Flush Mounting Ring

504-3.5.6 PRESSURE INSTRUMENT PIPING. Pressure instrument piping shall be installed in accordance with NAVSEA Drawing 803-1385850 and information provided in **NSTM Chapter 505, Piping Systems** and paragraph 504-2.4.

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504-3.5.7 CONNECTIONS

504-3.5.7.1 O-ring Union. 9/16-18 UNF-3A in accordance with MIL-G-18997. For new construction, retrofit and replacement pressure gages the standard pressure connection is the O-ring union connection. Each gage is furnished with a complete union consisting of the externally threaded end on the gage, the O-ring, the tailpiece, and the union nut.

504-3.5.7.2 O-ring Union. 7/16 -20 UNF - 2A in accordance with MIL-F-18866. For use in new and existing submarine applications service applications where conversion to an O-ring union connection is not appropriate.

504-3.5.7.3 Tapered Pipe Thread 1/4-18 NPT -2A for use with stem mounted pressure gages with ranges 0/100 psig or below (see MIL-STD-777).

504-3.5.7.4 1/2–Inch NPS Nickel-Copper Pipe Nipple, 6 Inches Long. In accordance with MIL-T-1368, Schedule 80. For oxygen systems where the gage is welded to adjacent piping.

504-3.5.7.5 O-ring Union (HEMPI Only). 7/16 - 20 UNF - 2B in accordance with MS16142. For HEMPI gages only, same connection as MILSPEC pressure transducers.

504-3.5.7.6 Threaded Vent. Caisson gage cases are open to ambient pressure through the bottom of the case. The vent is threaded to accept a 1/4-inch NPT male fitting.

504-3.5.8 FITTINGS AND ADAPTERS. Caisson gage cases are open to ambient pressure through the bottom of the case. The vent is threaded to accept a 1/4-inch NPT male fitting.

504-3.5.9 TUBING AND FITTING MATERIAL.

504-3.5.9.1 Copper-Nickel (70–30). Copper-nickel (70-30) material is used for wetted parts (fittings and tubing) where nonferrous, corrosion resistant, weldable material is required.

504-3.5.9.2 Corrosion-Resistant Steel. Corrosion-resistant steel is intended for wetted parts (fittings and tubing) where ferrous materials suitable for welding or brazing are required.

504-3.5.10 INSTRUMENT ISOLATION VALVES. Each pressure instrument should be provided with an instrument isolation or gage valve accessible to the operator for isolating the instrument should failure occur. Integral to the valve is a test connection on the valve stem for connecting pressure calibration equipment. Instrument isolation valves are in accordance with MIL-V-24578.

504-3.5.11 PRESSURE SNUBBERS. Pressure snubbers should be used when a pressure gage will be subjected to constant and rapid pressure fluctuations, which may damage the sensing element or make the gage difficult to read. For complete information on pressure snubbers see paragraph 504-2.5.

504-3.5.12 MATERIAL. MIL-G-18997 pressure gage cases are made of anodized aluminum, brass or corrosion resisting steel. The windows are acrylic plastic. Bourdon tube materials are either K-monel or Inconel Pressure sensing element assembly materials including Monel, Copper Nickel and Nickel Copper.

## 504-3.6 CARE AND MAINTENANCE

504-3.6.1 HANDLING AND OPERATION

504-3.6.1.1 Apply pressure slowly. Sudden opening of the gage valve may cause severe strain on the pressure sensing element, resulting in a reduction in expected life, damage, or failure. The rate of increasing pressure should be kept below 200 psig/sec to prevent possible hazardous conditions due to the diesel effect.

504-3.6.1.2 Avoid over pressure. Do not exceed the maximum pressure on the gage scale.

504-3.6.1.3 Where relief valves are used, ensure that the range of the gage is higher than the set pressure of the relief valve.

504-3.6.1.4 Avoid sudden pressure release. If the service is subject to sudden releases, use a pressure damper.

504-3.6.1.5 Keep gages to be used with oxygen or acetylene free from oil or any adhering hydrocarbon. When a gage is known to be contaminated with hydrocarbons, replace it with a new or cleaned unit (see paragraph 504-3.3.1).

504-3.6.1.6 tow spare pressure gages where they will not be subjected to moisture or severe shocks and jars. Stowed gages should be tagged with a label showing the date of cleaning, proposed use of the gage, and other pertinent information.

504-3.6.2 MAINTENANCE. When gages are removed periodically from their mounting, disassembled, and cleaned, extreme care in handling of components must be exercised so as not to bend or distort components and thus affect their operating efficiency.

**CAUTION**

**When gages are removed periodically from their mounting, disassembled, and cleaned, extreme care in handling of components must be exercised so as not to bend or distort components and thus affect their operating efficiency.**

### 504-3.7 CALIBRATION

504-3.7.1 CALIBRATION INTERVALS AND ACTIVITIES Unless malfunction necessitates repair and calibration more frequently, gages should be calibrated at definite intervals in accordance with:

a. Applicable Maintenance Requirement Card (MRC).

b. NAVSEA OD45845, Metrology Requirements List (METRL).

c. The calibration recall schedule (depending on the calibration maintenance system used on the ship).

d. The Shipboard Gage Calibration Program (SGCP).

e. Standard Maintenance Procedures (SMP) in the case of SSBN strategic systems.

504-3.7.1.1 Calibration in place or on-site by shipboard personnel using MRC or SGCP procedures and approved portable pressure calibration equipment is performed under the general direction of the Naval Field Calibration Activity (FCA) program. The FCA program has various phases, which describe the range of calibration activity permitted, the portable calibration equipment assigned to each phase, and the general administrative procedure required. FCA directives are contained in Naval Sea Systems Command Metrology and Calibration Program, NAVSEAINST 4855.6 and Field Calibration Activity Metrology Requirements List, NAVSEA OD 45854. Related to this NAVSEA calibration program is the program directed by the strategic systems Project Office (SSPO), Director for SSBNs. This calibration program is part of the SSPO Planned Maintenance Management Program (PMMP) and is administered under the Calibration Program for SSBN and FBM Tender Test and Measurement Equipment and FBM Tender Calibration Laboratory Standards, SSPO Instruction 4355.2.

504-3.7.1.2 Pressure gages requiring calibration at an Intermediate (I) or Depot (D) Level activity are removed from the system and delivered to either the I or D level activity as required by the MRC or SMP procedure or recall schedule. I level calibration activities are called Mechanical Instrument Repair and Calibration Shops (MIRCS). They are located in Tenders (Ads, Ass), repair ships (ARs), and other ship repair facilities. For SSBN tenders, the MIRCS counterpart is called a Fleet Mechanical Calibration Laboratory (FMCL). D Level calibration shops are located within Naval Shipyards under various descriptive titles, depending upon Naval shipyard organization and the precision level of calibration capability available.

504-3.7.2 CALIBRATION REQUIREMENTS

504-3.7.2.1 General. Pressure gages are most often calibrated by adjusting their mechanisms so the pointer gives accurate readings over the range of the gage. Accuracy is determined by checking the gage against a standard pressure source (calibrator) at several points up to full scale, then rechecking as the pressure is returned to zero. Some recommended practices are as follows:

1. Cycle the gage twice to full scale before testing.
2. Check the gage at four points upscale and down including the normal operating pressure.
3. The applied pressure should not overshoot when testing upscale or down. If it does, return to the previously checked point and continue from there.
4. Take readings after the gage is lightly tapped near the center of the dial so friction errors are minimized.

504-3.7.2.2 Calibration Instruments. There are various methods of applying a standard pressure to the gage being calibrated. The portable calibration standards used are described in Section 6. Dial gages must be calibrated in an upright position, except for special cases used in other positions. If a damper is used with the gage, it must be removed for the test. The connection between the test equipment and the gage must be tight because even a slight leak can cause an appreciable error.

504-3.7.2.3 Calibration Fluids. Gages calibrated at I or D level calibration activities may be calibrated only with dry nitrogen, air or certain liquids that are compatible with the gage service fluids. These precautions are taken to minimize contamination of gages and the systems in which they are to be installed. Certain portable calibration equipment used for in-place or on-site calibration use dry nitrogen, air, distilled water, or oil as the pressurizing medium. Fluid separators are used to prevent contamination of the system or calibration equipment when using some portable calibrators.

504-3.7.2.4 Cleaning Requirements. Three levels of cleaning are currently used for Naval pressure gages. These are:

a. Cleaning for general applications.
b. Cleaning for Oxygen service.
c. Cleaning for Divers air applications.

504-3.7.2.4.1 When a pressure gage is removed from the installed position to undergo corrective maintenance, it must be cleaned to prevent contamination of the test equipment. The term clean pertains to the internal surfaces of the gage, which is exposed to the service fluid.

504-3.7.2.4.2 Depending on the service fluid used the internal surfaces must be cleaned to the appropriate degree of cleanliness.

504-3.7.2.5 The Mechanical Instrument Repair and Calibration Shops (MIRCS) on tenders and repair ships include facilities, equipment and trained personnel for cleaning pressure gages from shipboard oxygen gas systems and from other shipboard pressure systems requiring equally stringent cleanliness (for example, nitrogen gages used in purging of the oxygen system or generator). These gages must be calibrated only by certified personnel using calibration equipment or standards that have been especially cleaned and dedicated to this purpose in accordance with NAVSEAINST 4855.9.

504-3.7.2.6 In place and on-site calibration of oxygen gages shall be performed in accordance with the requirements contained in Oxygen Gas System In-Place and On-Site Calibration of Pressure Instruments (Other Than Generating Plants), NAVSEA 0987-LP-022-3010. These instructions pertain to other than submarine electrolytic oxygen generators. In-place calibration of the submarine electrolytic oxygen generator gages and system piping is covered in applicable MRCs under the Planned Maintenance System (PMS) due to variations of generator and piping configurations. In either case, calibration of oxygen system gages must prevent contamination and can be performed only by certified personnel using approved calibration standards.

504-3.7.2.7 Pressure gages from submarine electrolytic oxygen generators, or other oxygen gages that cannot be calibrated in-place or on-site using appropriate MRC procedures for maintenance of electrolytic oxygen generators, are to be removed from the system by qualified IMA or D Level personnel and sent to a calibration facility certified to calibrate, detect unacceptable contaminants, and clean oxygen gages. The certified calibration facility should process, clean, package and label the oxygen gages in accordance with the instructions contained in Operation and Certification Requirements for Fleet Mechanical Instrument Calibration Activities, NAVSEAINST 4855.9. The gages are to be calibrated in accordance with the instructions contained in Pressure Gages and Switches, Oxygen Gas Systems, Instrument Calibration Procedures, NAVAIR 0817-LP-170-7000.

504-3.7.3 FLUID SEPARATORS. These devices are designed to separate system fluids from the calibration pressurizing medium. The separators available for various common fluid services should always be used when in-place or on-site calibration takes place and when calibration pressurizing medium and service pressure mediums are not compatible. A general guide to the type of fluid to be used for various gages is given in Section 2, Table 504-2-5.

504-3.7.4 ADJUSTMENT OF GAGES. Although this discussion is directed primarily toward calibration of dial type Bourdon tube gages, the principle may be applied to other mechanisms as well. For a particular gage, detailed methods should be obtained from the related NAVSEA or manufacturers manual. In addition, Instrumentman 3 & 2, NAVEDTRA 10193 and Instrumentman 1 & C, NAVEDTRA 12202 contain detailed procedures for gage calibration. The significant points to observe when adjusting a gage being calibrated are discussed in paragraphs 504-3.7.4.1 through 504-3.7.5.

504-3.7.4.1 Span Adjustment. If the pointer of a gage travels too far or not far enough, as each increment of test pressure is applied, the fault must be corrected by altering the linkage to change the ratio of movement between the pressure element and the pointer. Movement of the sector gear and therefore, of the pointer, is reduced by lengthening the distance between the pointer spindle and the link connection to the sector gear. The sector gear must engage the pinion on the pointer spindle for somewhat more than full travel of the pointer.

504-3.7.4.2 Zero Adjustment. To adjust the pointer when the increment increase or decrease is correct, but the reading is wrong, the pointer must be reset. This is done by either removing the pointer and replacing it in the proper position, or by an adjustment screw on the pointer which enables an adjustment without removing the pointer.

504-3.7.4.2.1 When the pointer must be removed, a pointer puller should be used. Replace the pointer carefully to avoid damage to it and the gage.

504-3.7.4.2.2 If it is not possible to make the gage read correctly over the entire scale, adjust the gage so the reading at the working pressure is correct. Make a table or curve showing the correction to be applied for other readings. This is a calibration table or curve and should be used in determining the correct reading.

**NOTE**

Internal adjustment to gages should not be accomplished by the gage user or FCA personnel. Out of tolerance or defective gages should be replaced. Replaced gages should be sent to the IMA for repair, adjustment, or disposal depending upon the Force Commander maintenance policy or as directed by the MRC.

504-3.7.4.2.3 Allowable Errors. Ambient conditions at the location of the gage cause errors in readings, which generally may be corrected by zero adjustment under operating conditions in accordance with the applicable MRC procedures. For acceptance, the accuracy limitations described in paragraph 504-3.5.3 apply.

504-3.7.5 FLUID HEAD CORRECTION. Fluid head correction will be required for liquid service gages when elevation difference between the gage and root connection to the pressure source is equal to or greater than 1 percent of normal operating pressure. See paragraph 504-2.6.

## SECTION 4.

## DIFFERENTIAL PRESSURE GAGES

### 504-4.1 ENGINEERING PRINCIPLES

504-4.1.1 Differential pressure (DP) gages are used to measure differential pressure, gage pressure, tank level, and flow. Most of the DP gages used onboard Navy ships are the dual-bellows type, manufactured by ITT Barton. While gages of other manufacturers are also used in shipboard applications, this section concentrates on the operation and maintenance of the ITT Barton gages. Pressure is applied to both the low and high pressure chambers of a dual-bellows differential pressure unit (DPU). The pressure differential between the two chambers converts linear motion of the bellows assembly to rotary motion of the indicating mechanism and the indicating pointer. The different measurements (differential pressure, gage pressure, tank level, flow) are accomplished by altering the basic configuration and installation of the gage.

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## 504-4.2 DEFINITIONS

504-4.2.1 DIFFERENTIAL PRESSURE. Differential pressure is the algebraic difference between two pressures measured with respect to a common basis.

504-4.2.2 OPERATING PRESSURE. Operating pressure is the pressure, under normal operating conditions, of a system in which the gage is installed.

504-4.2.3 SAFE WORKING PRESSURE (SWP). Safe working pressure is the maximum pressure under which the DP gage will remain operational. Safe working pressure is also termed ″housing pressure rating″.

504-4.2.4 INDICATOR. A DP gage is identified as an ″indicator″ when the indication is displayed locally on the gage dial.

504-4.2.5 SWITCH. A DP gage is identified as a ″switch″ when the gage is outfitted with high and/or low switches to detect system operating limit conditions.

504-4.2.6 TRANSMITTER. A DP gage is identified as a ″transmitter″ when electronic transmitters and repeaters are used to accomplish remote visual indication.

504-4.2.6.1 A DP gage can be characterized as an ″indicator″, a ″switch″, a ″transmitter″, or a combination of any or all of these terms depending on its function. For example, a DP gage that measures the differential pressure across a filter and displays that measurement on the gage dial is identified as an ″indicator″. A DP gage that displays water level locally on the gage dial, contains a low water level switch/alarm, and contains electronic transmitters for remote visual indication is identified as an ″indicator/switch/transmitter″.

504-4.2.7 DIFFERENTIAL PRESSURE UNIT (DPU). The DPU is the pressure-sensing assembly that consists of paired low pressure and high pressure chambers, and low pressure and high pressure bellows assemblies.

504-4.2.8 SENSOR. A sensor is a separate bellows and housing that is used to sense pressure at a remote location and transfer that pressure through capillary tubing to the DPU.

504-4.2.9 SEALED SENSOR SYSTEM. A sealed sensor system consists of one or two sensors, fill fluid, capillary tubing, and a DPU. The fill fluid contained in the sealed sensor system hydraulically transfers the pressure from the sensor(s) to the DPU. Each sensor contains a sealed bellows or diaphragm that serves as the separating member between the process media and the fill fluid.

504-4.2.10 BELLOWS UNIT ASSEMBLY (BUA) RANGE. The BUA range is the known system pressure sensing and operating range that the DPU can detect or measure safely without rupturing from over-pressure.

504-4.2.11 CALIBRATED RANGE. The calibrated range is the measurable pressure range as indicated on a gage dial.

## 504-4.3 SAFETY

504-4.3.1 HOUSING PRESSURE RATING. Housing pressure rating, also termed ″safe working pressure″, is the maximum pressure under which the DP gage will remain operational. The housing pressure rating of a gage is one of the parameters used to determine the correct gage for a specific application.

504-4.3.2 OPERATING PRESSURE. Operating pressure is the pressure, under normal operating conditions, of a system in which the gage is installed.

504-4.3.3 O-RING FITTINGS. DP gages have internally threaded (female) o-ring seal type (7/16-20 UNF) pressure connections. Adapters are used to mate the internal threads of the DP gage to the instrument piping.

## 504-4.4 DESCRIPTION

504-4.4.1 DIFFERENTIAL PRESSURE UNIT (DPU). The DPU is illustrated in Figure 504–4–1. The DPU is a dual bellows assembly enclosed within low and high pressure housings. The rupture-proof bellows assembly consists of a pair of bellows, a center plate, over range valves, a temperature compensator, a torque tube assembly, a pulsation damper valve, and a range spring assembly. The flexible metal bellows are mounted on opposite sides of the center plate and are contained within the low and high pressure housings. The outer ends of the bellows are sealed and are rigidly connected internally by means of a stem passing through an annular passage in the center plate. Opposed over range valves, located on the stem, are arranged to close against metal seats in the center plate and seal with o-rings. The bellows and center plate are completely filled with non-corrosive, low viscosity turbine oil. (This turbine oil is completely isolated from the process media.) In operation, the difference in pressure in the low and high pressure housings causes the bellows assembly to move towards the lower pressure in the low pressure housing, extending the range spring assembly. The bellows movement stops when the pressure is equalized within the low and high pressure housings. This linear motion of the bellows assembly is converted to a rotary motion by the torque tube assembly, which drives the indicating mechanism and pointer.

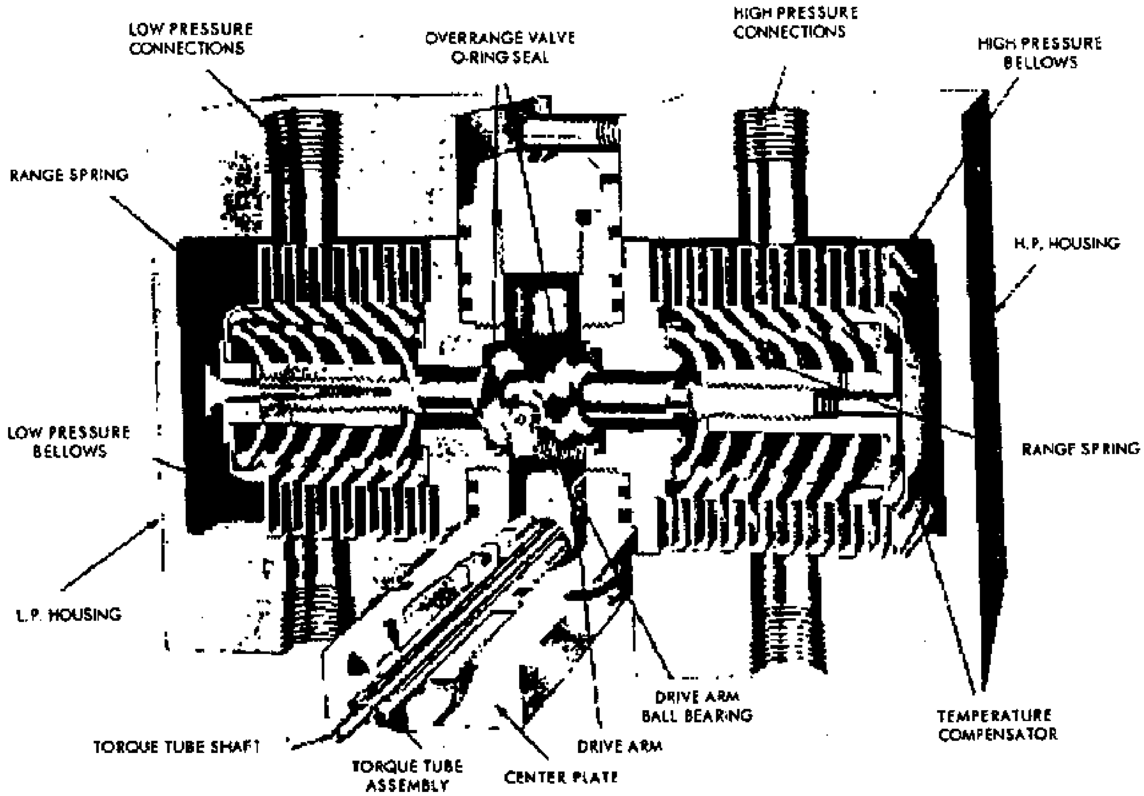


Figure 504-4-1. Differential Pressure Unit

504-4.4.1.1 Should the bellows assembly be subjected to a pressure difference greater than the differential pressure range of the gage, the bellows will move through the calibrated travel range and a small amount of over travel until the over range valve seals against its seat. As the over range valve closes, it ″traps″ the fill fluid in the bellows, thus preventing further travel. The entrapment of the non-compressible fill fluid also supports the bellows assembly and prevents it from rupturing.

504-4.4.2 BELLOWS. The bellows are constructed of individual diaphragms, stamped and formed from 316 stainless steel or beryllium copper, and assembled by highly specialized techniques. The bellows have exacting linearity characteristics, as well as long cycle life, free from the effects of work hardening commonly encountered with the hydraulically formed or mechanically rolled types.

504-4.4.3 PRESSURE HOUSINGS. Each pressure housing has two tapped connection ports; one port is located on the top of each housing; the other port is located on the bottom of each housing. The pressure housings may be rotated 180 degrees to facilitate connection at the top of the housing for venting when used in gas service, or at the bottom to provide draining when used in liquid service. The pressure housings are available in various safe working pressure ratings. The high pressure housing is connected by pipe or tubing to the high pressure side of the system being measured. The low pressure housing is connected by pipe or tubing to the low pressure side of the system being measured.

504-4.4.4 TEMPERATURE COMPENSATION. A free-floating bellows, attached and connected by a passageway to the end of the high pressure bellows, provides for temperature compensation. This free-floating bellows acts as an expansion chamber and allows the fill fluid to expand and contract with changes in temperature without changing the pressure within the bellows assembly or the physical relation between the two opposing bellows. This mechanism minimizes the zero shift in indication that would otherwise occur with changes in temperature.

504-4.4.5 PULSATION DAMPER VALVE. The pulsation damper valve is an adjustable needle valve that controls the flow rate at which the fill fluid transfers between the high and low pressure bellows. An accurately-fitting floating ring on the high pressure bellows side prevents the fill fluid from passing directly from one bellows to the other, ensuring control since all the transferring fluid flows through the damper passage. The damper is adjustable for a response time between a few seconds to several minutes for full scale travel of the bellows. The pulsation damper valve prevents the effects of erratic water level, erratic system pressure, and ship roll and pitch from adversely affecting the indicator readings.

504-4.4.6 TORQUE TUBE ASSEMBLY. As shown in Figure 4–2, the torque tube assembly consists of a thin-walled tube, a shaft, and supporting components. The outboard end of the tube is sealed and rigidly attached to the center plate. The torque tube shaft passes through the center of the tube and is welded to the inboard end of the tube. The linear motion of the bellows rotates the inboard end of the tube via the drive arm; the torque tube twists since its outboard end is fixed. The shaft, which is freely supported within the tube at the outboard end but welded at the inboard end, rotates through the same angle as the drive arm. This configuration provides a leak-free, packless, self-lubricating, corrosion-free rotary transmission of the bellows movement that maintains a high degree of sensitivity without friction degradation.

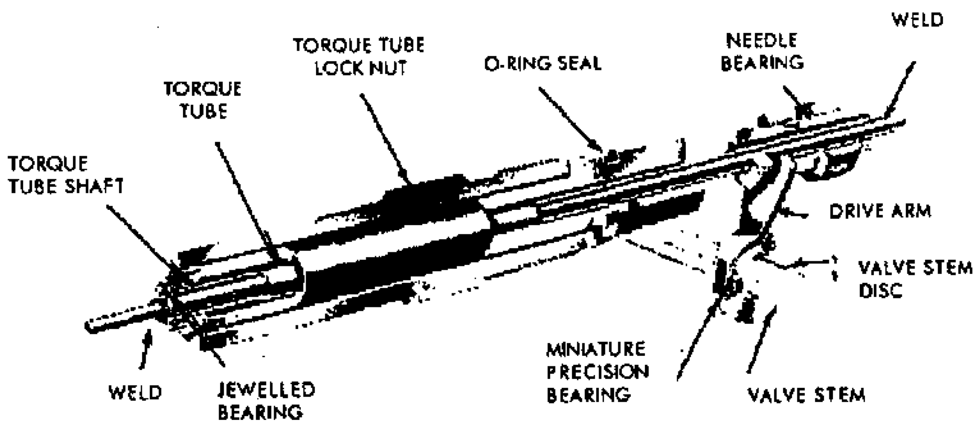


Figure 504-4-2. Torque Tube Assembly

504-4.4.7 DIAL INDICATOR MOVEMENT. The rotation of the torque tube shaft drives a differential drive arm in the dial indicator movement. The differential drive arm, by means of mechanical linkage and a gear and pinion arrangement, multiplies the approximate 8 degree rotation of the DPU output shaft to provide 270 degree rotation of the indicator pointer. Mechanical adjustments enable precise calibration of the pointer movement so that the measured difference in pressure is accurately indicated on the front panel scale plate.

504-4.4.8 SWITCHES/RELAYS. Depending on the application, DP gages may be outfitted with high and/or low snap-action switches. The torque tube shaft provides drive to a switch actuating cam in the switch assembly. Individual high and low limit detection switches are mounted on adjustable assemblies that permit high and low limit reporting over the entire indicating scale range. Cam followers, attached to the switches, ride on the switch-actuating cam surface. When cam rotation places the follower on the high portion of the cam, the plunger of the associated limit switch is mechanically actuated to signal that a prescribed limit has been exceeded. Switch contact life is influenced by various application conditions such as temperature, humidity, airborne contamination, vibration, amount of plunger travel, cycling rate, and rate of plunger travel, as well as by the electrical circuit characteristics. All gages employing snap-action switches may be furnished with one or two relays mounted within the case. The addition of a relay allows greater flexibility of switching action and increased current handling capacity without the need for external mounting and wiring. This feature is often of considerable importance where explosion-proof housings are required.

504-4.4.9 ELECTRONIC TRANSMITTERS. The electronic transmitter is basically a loop current regulation device in which the loop current is controlled by a mechanical force or motion. As with the indicator movement and switch assembly, the DPU torque tube output shaft drives the input to the electronic transmitter. To provide the input signal to the electronic transmitter, a drive block transmits the torque tube shaft rotation to the ball bearing on the end of a cantilever beam end to which piezoresistive strain gages are bonded on opposite sides. Shaft rotation causes proportional beam bending, applying tension on one strain gage and compression on the other. The strain gage in tension increases in resistance, and the strain gage in compression decreases in resistance. The two gages are wired into the transmitter circuits as two active arms in a balanced bridge circuit. The bridge output signal is conditioned and converted by the transmitter circuits to a 4 to 20 mA output signal that is proportional to the DP applied to the DPU.

504-4.4.10 EXTERNAL BELLOWS SENSING ELEMENT. An external bellows sensing element is a sealed bellows encased in a pressure housing and a length of tubing. The bellows, housing, and tubing are evacuated and liquid-filled at the factory. Measurement or control of corrosive, high temperature, or dangerous fluids, and installations where gage lines are subject to freezing, clogging, condensate formation, gas entrapment, and hydrate formation, are typical applications for a filled system. In liquid level applications, the need for a reference leg is eliminated as the external bellows sensing element also serves this purpose.

504-4.4.11 FILL FLUIDS. The sealed sensor systems are available with various fill fluids that are specified depending on the application in which the system is to be used. The fill fluids that are used for Naval applications are distilled water in systems where contamination of the process media is a concern, such as potable water systems; ethylene glycol and water in systems where low temperatures (freezing) are a concern or a matching of specific gravity is desired, such as seawater systems; and turbine oil for all other applications. The fill fluid in the sealed sensor system is completely isolated from the fill fluid in the bellows of the DPU.

504-4.4.12 PRESSURE SENSING PORTS/VENT PORTS. Each pressure housing has two tapped connection ports; one port is located on the top of each housing; the other port is located on the bottom of each housing. The pressure housings may be rotated 180 degrees to facilitate pressure connection at the top of the housing and venting at the bottom when used in gas service, or pressure connection at the bottom of the housing and draining at the top when used in liquid service. The ports are internally threaded (female) o-ring seal type (7/16-20 UNF).

504-4.4.13 VALVES. A valve manifold is used in the sensing lines between the system root connections and the DPU to facilitate operation and investigation of the gage.

## 504-4.5 OPERATION

504-4.5.1 SELECTION. There are a number of parameters that must be considered in order to determine the correct DP gage for an application, such as type of measurement required (differential pressure, gage pressure, tank level, or flow), gage configuration (indicator, switch, transmitter), system differential pressure, system operating pressure, safe working pressure of the gage, and gage installation.

504-4.5.2 ACCURACY. The DP gage military specification, MIL-G-24659, requires an accuracy of plus or minus one percent of span for gages without switches or with switch contacts disengaged, plus or minus 1-1/2 percent of span for gages with switch contacts engaged, and plus or minus three percent of span at the point of switch actuation. The accuracy of the switch setpoint shall be plus or minus one percent of span.

504-4.5.3 INSTALLATION. The DP gage can be panel, pipe, or bulkhead mounted, depending on the application. In general, the distance between the differential pressure source and the DP gage should be as short as possible; distances exceeding 100 feet are not recommended. 1/4-inch pipe or tubing is used for distances less than 50 feet; 1/2-inch pipe or tubing is used for distances between 50 and 100 feet.

504-4.5.3.1 All piping shall be sloped at least one inch per linear foot to avoid liquid or gas entrapment. The DPU or dial indicator movement should not be subjected to temperatures in excess of 200°F or below 32°F. Where severe pressure pulsations exist, a suitable pulsation damping device shall be installed upstream of the DPU. The DPU shall be mounted on a solid support to minimize vibration. All sensing lines (tubing) shall be supported to minimize vibration. All piping joints shall be leak tight. A valve manifold connecting the differential pressure source and the DPU shall be installed.

504-4.5.4 APPLICATIONS. For differential pressure measurement, both the low and high pressure chambers receive pressure from two separate pressure sources, such as the low pressure and high pressure sides of a filter or strainer. Similarly, gage pressure measurement is accomplished by exposing the high pressure chamber to system pressure and the low pressure chamber to atmospheric pressure.

504-4.5.4.1 A typical application for gage pressure measurement using a DP gage is the Sonar Dome Rubber Window (SDRW) pressure. Tank level measurement is accomplished by installing a low pressure external bellows sensing element at the bottom of the tank and a high pressure external bellows sensing element at the top of the tank. These elements are connected to the low and high pressure chambers, respectively, of the DP gage. The difference between the low and high pressure indications is inversely proportional to the level of liquid in the tank; i.e., as the liquid level decreases, the pressure differential increases. (This type of gage is known as a reverse-acting gage.) This liquid level measurement is then converted to an electrical signal and transmitted to a remote readout display. DP gages that are used for tank level applications are often outfitted with a low level switch that activates a low level alarm. For flow measurement, the low pressure and high pressure chambers receive pressure from either side of a venturi, orifice plate, flow tube, or other primary device located in the system piping.

504-4.5.5 REVERSE-ACTING GAGES. When the differential pressure sensing technique is used for liquid level measurement, a reverse-acting gage is used. The pointer of a reverse-acting gage is set up to rotate counterclockwise with increasing differential pressure and clockwise with decreasing differential pressure. This rotation is the reverse of the pointer rotation in a normal DP gage. For liquid level measurement, the high pressure chamber of the DP gage is connected to the top of the tank. This pressure is the tank reference pressure. The low pressure chamber is connected to the bottom of the tank. This pressure, the head pressure of the liquid in the tank, varies with the liquid level in the tank. As the liquid level in the tank decreases, the differential pressure increases, which in turn causes counterclockwise rotation of the pointer. As the liquid level increases, the differential pressure decreases and causes clockwise rotation of the pointer. The scale markings of a reverse-acting liquid level gage (for example, 10-N-10) represent inches of water column (IWC) below normal tank level, normal tank level, and IWC above normal tank level.

504-4.5.6 DETERMINATION OF CALIBRATION DATA. Due to the variety of applications for which DP gages are used, information about the specific system in which the gage is installed is required prior to calibration. For differential pressure and gage pressure applications, system pressure is measured directly and is displayed on the gage dial. For sealed sensor systems, the head pressure of the fill fluid (determined by multiplying the specific gravity of the fill fluid by the vertical length of tubing between the sensor and the DPU) is required to properly offset the indication of the gage prior to connection to the sealed sensor system. For tank level applications, the differential pressure in the tank is measured but is displayed in terms of ″normal″ tank level, or deviations thereto, on the gage dial. This translation from differential pressure to tank level (determined using the head pressure of the fill fluid) is established and verified during gage calibration. For flow applications, the differential pressure across the primary device is measured but displayed as a flow rate on the gage dial. A ″differential pressure to flow rate″ conversion factor, based on the properties of the process media and the size of the system piping, is required. The translation from differential pressure to flow rate (using the appropriate conversion factor) is established and verified during gage calibration.

## 5044-4.6 CARE AND MAINTENANCE

504-4.6.1 GENERAL MAINTENANCE. Recommended preventive maintenance procedures to be performed on a scheduled basis are provided in Planned Maintenance System (PMS) documentation. These maintenance procedures are outlined on the appropriate Maintenance Requirement Cards (MRCs) and technical manuals for the instrument and the application. Periodic inspection of the integrity of the DPU piping is recommended to locate any leaks that may affect the accuracy of the DP gage indication. DP gages used in services where solids or semi-solids may accumulate in the pressure housings require periodic inspection and cleaning to ensure optimum operation of the gage.

504-4.6.2 GENERAL TROUBLESHOOTING. In the event of an incorrect DP gage indication, ensure that the principal system is operating properly prior to any troubleshooting or repair to the gage. An erroneous DP gage indication suggests that there is a leak in either the high or low pressure tubing, that the vacuum fill has been breached and there is air trapped in the tubing, that the bellows movement has been restricted by debris in the housing, that corrosion or dirt is fouling the mechanism or movement, or that the pointer is either loose or dragging on the scale plate. The technical manual for the instrument and the application contains information on troubleshooting and corrective action, however, the actual repair procedures are often complicated and require specialized equipment and expertise to accomplish. In such cases, trained personnel should perform the necessary repair and calibration procedures.

## 504-4.7

504-4.7.1 GENERAL METHOD. All system securing and tag-out procedures shall be performed prior to calibration of the gage. The specific procedures for calibrating the Barton DP gage are outlined in the applicable technical manual. However, the general method of calibration for all DP gages, regardless of the application, is the same. The gage is isolated from system pressure and the high pressure housing is connected to a calibrated portable pressure source. The low pressure housing is vented to atmosphere.

504-4.7.1.1 For gages employing sealed sensor system(s), the high pressure sensor housing is placed in a special test housing and is connected to a calibrated portable pressure source. The calibrated pressure source is connected to the remote high pressure sensor housing so that calibration of the system, not just the gage, is accomplished. The calibrator is used to apply pressure to the sensor to simulate filling and emptying the tank. The remote low pressure sensor housing is vented to atmosphere. Using the calibrated pressure source, the gage is cycled twice through its full pressure range by increasing and decreasing the applied pressure, to remove any hysteresis. Reference measurements are made at five equally spaced intervals over the entire range (both upscale and downscale). Precaution is taken to avoid pressure overshoot. Should overshoot occur, the pressure is restored to the previous reference point and the procedure is continued. Readings are taken at each reference point before and after the center of the gage dial is tapped in order to determine any friction error. Depending on the results of the above reference measurement, appropriate adjustment or repair to the gage is performed. A final reference measurement, in accordance with the above procedure, is conducted to ensure that the gage satisfies the specified accuracy requirements.

504-4.7.2 EQUIPMENT. On-site calibration of DP gages requires the applicable calibration procedure (MRC, SGCP or NAVAIR 17-20MP-XX Series ICP), a portable calibrated pressure source (equipped with a test gage of at least a 0.25 percent accuracy), an ITT Barton tool kit, various common tools, and a spare sensor housing (for sealed sensor systems). Should repair of the DP gage be necessary for calibration to be accomplished, a vacuum fill kit, vacuum pump, vacuum gage, spare fill fluid, and various repair parts are required.

504-4.7.3 CALIBRATION INTERVALS. Calibration intervals are assigned in accordance with NAVSEA's Metrology and Calibration Program and the Field Calibration Activity Metrology Requirements List, based on the criticality of the system in which the gage is installed. Common calibration intervals are twelve and eighteen months. There are applications for which calibration of the gage is required at time of use or calibration of the gage is not required. Should problems occur with the gage, repair and calibration may be required before the assigned calibration interval has expired.

## SECTION 5.

## PRESSURE TRANSMITTER

### 504-5.1 ENGINEERING PRINCIPLES

504-5.1.1 GENERAL. Pressure transducers are sensors that convert a measured pressure into an electrical output signal that is proportionate to the input pressure.

504-5.1.2 TYPICAL USE. Pressure transducers are typically used in shipboard applications where a remote reading of a pressure indication is required, or when an electrical signal representing a pressure is required for input into a control system, or data acquisition system, or a data recording device.

504-5.1.3 MISSION CRITICAL APPLICATIONS. For mission critical applications, i.e., main propulsion plant controls, pressure transducers are usually specified in accordance with MIL-P-24212,**Pressure Transducer Equipment** or MIL-D-24304 **Differential Pressure Transducer Equipment** . Additionally, MIL-T-24742 **Transducer, Pressure and Differential Pressure** , Miniature covers a new generation of pressure transducers distinguished by their small physical size. The form, fit and function of these pressure transducers are tightly controlled by the Military Specifications which are Naval Sea Systems Command (NAVSEA) documents.

504-5.1.3.1 For less critical applications such as data acquisition, remote pressure readings, and inputs to data recording devices, commercially available pressure transducers are utilized. These transducers are used extensively in the recently developed Integrated Condition Based Monitoring System (ICAS). Commercial pressure transducers are used in this application since they are relatively inexpensive, and the data collected is used primarily for trending. As a result, the absolute accuracy of the transducer is not as critical as it would be in other applications, and the performance characteristics are considered adequate in this installation.

504-5.1.4 PRESSURE TRANSDUCER COMPONENTS. Pressure Transducer Components. Pressure transducers typically consist of three major components: the enclosure, the pressure sensing element, and the signal conditioner. The pressure sensing element (force summing device) converts either gas or liquid energy into a physical (mechanical) displacement. The pressure sensing element may be a diaphragm, convoluted diaphragm, or a bellows. The majority of modern pressure transducers utilize a diaphragm.

504-5.1.5 TRANSDUCTION PRINCIPLES. Transduction Principles. Force summing devices can be coupled to a variety of electrical devices for converting mechanical displacement into electrical signals. In general, the mechanical travel required by each type of sensor dictates the selection of the force summing element. Pressure transducers are based primarily upon the following methods of transduction:

a. Capacitive

b. Differential Transformer

c. Inductive

d. Piezoelectric

e. Potentiometric

f. Strain Gage

504-5.1.6 CAPACITIVE ELEMENT. A diaphragm positioned between two fixed plates is deflected, causing capacitance change in two circuits. If the dielectric of the capacitor is maintained constant or compensated for, a highly stable, very repeatable transducer is achieved. Small displacement of the capacitor-diaphragm is a major inherent advantage.

504-5.1.7 DIFFERENTIAL TRANSFORMER. A force summing device is often a diaphragm, but bellows and Bourdon tube designs are used where applications do not require exposure to high levels of shock or vibration. In most designs a push rod or linkage displaces a magnetic core within a transformer to produce unbalance within two secondary windings. The sensitivity of the transducer is a trade-off in design between the displacement of the transformer core and transformer-turns-ratio. Due to the relatively large core displacement required, this type of sensor is not employed where acceleration or vibration is present.

504-5.1.8 VARIABLE RELUCTANCE/INDUCTIVE SENSORS. Variable Reluctance/Inductive Sensors. A pair of coils excited by a carrier frequency are influenced by changes in magnetic coupling of a pressure driven armature which displaces or rotates between the two coils. The following two basic designs have developed around the variable reluctance design:

a. An armature driven by a Bourdon tube which rotates above a single ″E″ core with two coils.

b. A pressure displaced diaphragm positioned between two ″E″ cores alters the inductive loop between the coil on each ″E″ core.

504-5.1.8.1 The armature driven system is massive and is primarily used in secondary standard, stationary applications. The diaphragm configuration has a high natural frequency and is extremely rugged. A wide pressure range (0 - 0.1 psi through 0 - 10,000 psi, or higher) is available in this configuration.

504-5.1.9 PIEZOELECTIRC. Strain applied to asymmetrical crystalline materials generates an electrical charge. The piezoelectric effect has been used in a variety of instruments. Special ceramics and salts have been developed for special applications by various transducer manufacturers, but the basic principles are observed.

504-5.1.9.1 A force summing diaphragm is coupled to a selected axis surface of the crystal to induce strain. The high impedance output of piezoelectric devices requires a voltage or charge amplifier to match the sensor output with signal conditioning before transmission more than a few feet from the sensor. High frequency data and dynamic calibration of other kinds of pressure transducers are dependent upon these transducers.

504-5.1.10 POTENTIOMETRIC. A very active force summing pressure bellows or Bourdon tube is linked to a potentiometer wiper which travels across a multiturn wire coil or deposited resistor. Usually, some motion amplification between the force summing element and the wiper track across the resistance element is employed to improve resolution. Balancing mass is employed to minimize acceleration error. Friction between the wiper and resistance element plus some pivot bearing friction and wobble results in considerable hysteresis for measurements taken in a vibration-free environment. Vibration and pressure fluctuations cause agitation of the wiper resulting in fast wear of the resistor. For short term measurements where moderate accuracy is adequate, the potentiometric transducer offers several advantages. The resistance element can provide specialized output linearities (linear, sine, cosine, exponential, etc.). As a voltage ratio device, close regulation of the excitation voltage is not required. High-level output is inherent in the potentiometer concept, but output load impedance must be kept high to limit loading effects. Inexpensive potentiometer type pressure transducers can be produced, but their short life expectancy makes them an expensive selection for repeated or medium duration test measurements.

504-5.1.11 STRAIN GAGE. Of all the various types of transducers available, strain gage sensors are utilized more frequently for measurements than any other type of pressure transducer. There are several reasons for this including the following:

a. High accuracy

b. Flat frequency response from steady state to several thousand cycles over extended periods of time

c. Stable performance and reliable data output

d. Availability

e. Standardization of data signal conditioning and power supplies

In addition, manufacturers can adjust the output characteristics for the following:

a. Change in the zero output level

b. Full scale output level (sensitivity or span)

c. Temperature effects on zero

d. Temperature effects on zero (sensitivity or span)

e. Input/output impedance matching

504-5.1.11.1 Strain Gage Principles. Force (or diaphragm displacement) causes a change in position or change in length of the sensing element. In the unbonded element, a short length of wire is stressed by pulling on one end or deflecting the position of the mounting posts. The bonded strain gages are attached to the diaphragm or bending beam by means of an adhesive. Strain or shear is induced by the pressure sensor upon the wire or crystalline strain gage element. Each active element exhibits a resistance change, which is additive in effect, within a wheatstone bridge circuit.

504-5.1.11.2 Construction. The sensor of a bonded strain gage pressure transducer is usually wire or foil ribbon coated with a thin layer of insulation and cemented to the back-side of the diaphragm, or on a cantilever beam which is deflected by changes in the pressure sensing diaphragm.

504-5.1.11.2.1 Strain elements are laid out in special patterns to be sensitive in a single axis of deformation. They are mounted directly to the pressure sensing diaphragm on medium and high pressure range transducers. Low pressure range designs may incorporate a force rod between the pressure sensing diaphragm and beams to which the strain gages are bonded. To obtain more sensitivity at low pressures, larger diaphragms or bellows are required. The trade-offs between sensitivity and environmental effects on accuracy (vibration, acceleration, temperature) set the lower practical range limit.

504-5.1.11.2.2 The bonded gage exhibits a characteristic related to the bonding to diaphragms or beams. The adhesive between the gage and the surface to which it is attached may flow somewhat, resulting in slight shifts or repositioning of the gage at elevated temperatures. Through special attention in manufacturing, this characteristic can be minimized to achieve good repeatability and stability specifications.

504-5.1.11.2.3 The rugged construction of bonded strain gage transducers permits considerable abuse in handling and use where transient over-pressure would destroy other types of transducers. However, transducers subjected to rough handling and use may require recalibration as zero and sensitivity shifts will occur.

## 504-5.2 DEFINITIONS

504-5.2.1 ACCURACY. The ratio of the error to the full scale output, or the ratio of the error to the output, as specified, expressed in percent. Accuracy may be expressed in terms of the measurand (quantity or medium subject to being measured).

504-5.2.2 DRIFT. An undesired change in output over a period of time in which the change is not a function of the measurand.

504-5.2.3 ERROR BAND. The band of maximum deviations of the output values from a specified reference line or curve due to causes attributed to the transducer.

504-5.2.4 HYSTERESIS. A lag effect in the pressure transducer's output when the input pressure is varied. The specific definition is the maximum difference in output from any measurand within the specified period of time when the value is approached first with increasing measurand and then with decreasing measurand.

504-5.2.5 INPUT IMPEDANCE. The impedance measured across the excitation terminals of the pressure transducer.

504-5.2.6 LINEARITY. The closeness of a calibration curve with respect to a specified straight line.

504-5.2.7 RANGE. The measurand values over which a pressure transducer is intended to measure specified by their upper and lower limits.

504-5.2.8 REPEATABILITY. The ability of the transducer to produce consistent output readings when the same measurand value is applied to it consecutively, under the same conditions, and in the same direction.

504-5.2.9 SENSITIVITY. The ratio of the change in transducer output to a change in the value of the measurand.

504-5.2.10 SPAN. The algebraic difference between the upper and lower limits of the range of the pressure transducer.

504-5.2.11 STABILITY. The ability of the transducer to retain its performance characteristics over a specified period of time.

504-5.2.12 THERMAL COMPENSATION. The provision of a supplemental device, circuit, or special material(s) to counteract sources of error in pressure measurements resulting from temperature variations.

504-5.2.13 ZERO SHIFT. A change in the zero-measurand output over a specified period of time and at ambient conditions.

## 504-5.3 SAFETY

504-5.3.1 The following safety precautions should be observed when calibrating a pressure transducer.

504-5.3.1.1 Ensure that the pressure connection on the transducer is isolated from the process system by closing either the calibration or root valve, or both.

504-5.3.1.2 Slowly bleed any remaining pressure from the transducer prior to disconnecting the pressure connection.

504-5.3.1.3 Ensure that the fittings, hoses, calibrator and any other associated equipment are rated to withstand the pressures required to perform the calibration and are compatible with the transducer under test.

504-5.3.1.4 Remember that pressure transducers are electrical devices and are potential electrical hazards (particularly 4-wire units that are powered by 120 Vac). Deenergize the electrical circuit prior to removing or performing maintenance on the transducer. Observe all safety precautions, warnings, and tag-out procedures.

504-5.3.1.5 Be aware that pneumatic pressure contains far more potential energy than liquid pressure and can be very dangerous in large volumes.

504-5.3.1.6 Ensure that transducers used in oxygen systems are calibrated using only equipment items, including calibrators, hoses and fittings, that are approved for oxygen system component calibrations. Ensure that the transducer does not become contaminated after being cleaned and calibrated for oxygen service.

## 504-5.4 DESCRIPTION

### 504-5.4.1 TRANSDUCER TYPES

504-5.4.1.1 Absolute Pressure. Pressure measured relative to a vacuum. The reference side of the sensor is evacuated and sealed. If the pressure port is opened to ambient, the transducer will indicate approximately 14.7 psia. Typical uses of absolute transducers are altimeters and barometers.

504-5.4.1.2 Gage Pressure. Pressure measured relative to ambient pressure. The reference side of the sensor breathes air. Caution is advised as other contaminants, in addition to air, can enter the transducer, possibly causing failure. Additionally, blockage of the breathing port (typically paint on shipboard applications) may result in erroneous pressure indications. Liquid level and various other types of hydraulic pressure applications use this type of reference.

504-5.4.1.3 Sealed Gage. Pressure is measured relative to standard pressure (14. 7 psia). The reference side of the sensor is sealed and does not breathe. Therefore, contamination is not a concern as with gage pressure transducers. However, they are subject to variations in output due to changes in atmospheric pressure. It is not recommended for low pressure ranges where changes in ambient atmospheric pressure will have a greater effect on the output.

504-5.4.1.4 Vacuum. Pressure is measured relative to ambient pressure. It is similar to the true gage pressure reference type, but the pressure applied to the port is less than ambient. The transducer is wired to provide a positive output for increasing vacuum.

504-5.4.1.5 Differential. Differential pressure measurement is performed by accepting two independent pressure sources simultaneously. Transducer output is proportional to the difference between the two sources. Normally, if the pressure input is greater on the high side, the transducer will have a positive output. Equal pressure on both sides, also known as base pressure or null pressure, produces a zero output. Flowmeters and some liquid level sensors employ this type of transducer.

504-5.4.1.6 Compound Range. Compound range is another way pressure instrumentation can be calibrated. In this case the transducer will measure both vacuum and positive pressure. The pressure reference is the same as a true gage. It is important to specify where the zero balance is to be located. If the zero balance point is 0 psig, pressure will cause positive output and vacuum will cause negative output. The zero balance may also be placed at the lowest end of the scale range, in which case all output is positive. Transducers with a 4 to 20 mA output are set up in this manner as outputs below 4 mA are not possible.

504-5.4.2 PRESSURE CONNECTIONS. All military specified pressure transducers have a pressure connection that is in accordance with MS16142. Commercial units are typically 1/4 NPT. This type of connection (pipe thread) is only suitable for shipboard applications where the system pressure does not exceed 100 psig.

504-5.4.3 ELECTRICAL CONNECTORS. Military specified pressure transducers have a five-pin electrical connector that is manufactured in accordance with MS3452. Both the 2-wire and 4-wire pressure transducers use the same connector except that the connectors are keyed differently to prevent installing a 2-wire in place of a 4-wire unit or vice versa. Commercial units come in a variety of configurations and may be either connectorized or utilize a terminal block, pigtail or some other configuration.

504-5.4.4 ZERO AND SPAN ADJUSTMENTS. Military specified pressure transducers are required to have non-exposed adjustments for zero and span. These screw type potentiometers are located inside the enclosure and require the cover to be removed to access the adjustments. Only qualified personnel with the appropriate calibration equipment should attempt adjusting a pressure transducer.

504-5.4.5 FLUID MEDIA COMPATIBILITY. Pressure transducers that are qualified for use in salt water applications can be used for general purpose applications since the inconel or monel used in the wetted parts are compatible with all the fluid media typically encountered in general purpose applications. The reverse is not true. That is, pressure transducers that are qualified for use in general purpose applications can not be used in salt water applications since the material used in the wetted parts is not compatible with salt water, and will result in eventual failure of the transducer. Transducers intended for flue gas and ammonia or oxygen applications should be used for these services exclusively and can not be interchanged with other transducer applications.

## 504-5.5 OPERATION

504-5.5.1 OPERATING ENVIRONMENT. The operating environment for the various types of pressure transducers will normally be shipboard engineering spaces. The many applications include, but are not limited to, engine monitoring, HVAC, compressors, pneumatic control systems, chiller/boiler differential pressure, main propulsion plant controls, tank liquid level, pump differential pressure, and filter/strainer differential pressure. These transducers depending on their particular construction can be used to monitor corrosive and non-corrosive gas and liquid flow.

504-5.5.2 OPERATIONAL REQUIREMENTS. The operational requirements of a pressure transducer are determined by the characteristics of the system to be monitored as well as the operating environment. Selecting the right pressure transducer requires knowledge of both the operating system and the various types of transducers available. Typical information required for selecting a pressure transducer includes the following:

a. System operating pressure range

b. Over-pressure protection

c. Output accuracy required

d. System operating temperature range

e. Frequency response

f. Exposure to shock and vibration

g. Installation requirements

h. Environmental hazards

i. Fluid media compatibility

j. Performance stability

k. Type of output (mV, V, mA)

504-5.5.3 MIL-SPEC PRESSURE TRANSDUCER DESIGNATIONS. A MIL-SPEC part number is assigned to each possible configuration of pressure transducer. This part number is printed on the label affixed to the exterior of the transducer enclosure (housing). The MIL-SPEC part number should be of the following form:

″PGT-GP-100-G-2″

| | | |
|---|---|---|
| PGT | = | Type |
| GP | = | Application |
| 100 | = | Range |
| G | = | Reference |
| 2 | = | Power Supply |

504-5.5.3.1 Type. Transducer type shall be designated by a three letter symbol as follows:

| | | |
|---|---|---|
| PGT | - | Pressure, gage, transducer |
| PVT | - | Pressure, vacuum, transducer |
| PCT | - | Pressure, compound, transducer |
| PWT | - | Pressure, water column, transducer |
| PDT | - | Pressure, differential, transducer * |

* PDT type transducers do not contain a ″reference″ field in their part number, but do have a ″unit″ field to indicate the units designated by the range, either PSID or WCD (in H20), and a ″pressure rating″ field.

504-5.5.3.2 Application. Fluid pressure to be measured shall be indicated as follows:

| | | |
|---|---|---|
| GP | - | Steam, oil, fresh water, condensate, and gases not listed below |
| SW | - | Seawater |
| FG | - | Flue gas and ammonia |
| OX | - | Oxygen |

504-5.5.3.3 Range. Table 504-5-1 specifies the standard ranges for the various types of MIL- SPEC pressure transducers other than the differential pressure type. These are the standard ranges. The MIL-SPEC does allow for ranges other than those listed for unique applications.

**Table 504-5-1.** PRESSURE TRANSDUCER RANGES

| **Type PGT** | **Type PCT** | **Type PVT** | **Type PWT** |
|---|---|---|---|
| **PressureRange(psig)** | **PressureRange(in. Hg. psig)** | **PressureRange(in. Hg)** | **PressureRange(in. $H_2$ O)** |
| 0 - 50 - 150 - 300 - 500 - 600 - 750 - 1000 - 1500 - 1500 - 2000 - 3000 - 5000 - 6000 - 10000 - 15000 - 30000 - 50000 - 60000 - 10000 | 0 - 30.0 - 150 - 30.0 - 300 - 30.0 - 1000 - 30.0 - 150 | 0 - 30 | 0 - 100 - 600 - 1500 - 300 |

504-5.5.3.3.1 Table 504-5-2 specifies the standard ranges for MIL-SPEC differential pressure transducers. These are the standard ranges. The MIL-SPEC does allow for ranges other than those listed for unique applications.

**Table 504-5-2.** DIFFERENTIAL PRESSURE TRANSDUCER RANGES

| **Type PDTPressure Range(psid)** | **Type PDTPressure Range(in. $H_2$ O)** |
|---|---|
| 0-150-300-600-1000-2000-4000-600 | 0-100-600-1500-300 |

504-5.5.3.3.2 Pressure Rating. The following listed values specify standard pressure ratings for MIL-SPEC differential pressure transducers.

Standard Pressure Rating (psi)

150600150030006000

504-5.5.3.3.3 For MIL-SPEC pressure transducers other than the differential pressure transducers, these units are rated to withstand 200% of their pressure range (10,000 psig max) without any deviations greater than 1% of the previous calibration values.

504-5.5.3.4 Reference. The reference pressure shall be one of the following:

G - Atmospheric (gage)A - Vacuum (absolute)S - Sealed reference at 14.7 psia

504-5.5.3.5 Power Supply. The power supply wiring shall be one of the following:

2 - Two-wire system (28 Vdc supplied)4 - Four-wire system (120 Vac supplied)

## 504-5.6 CARE AND MAINTENANCE

504-5.6.1 FLUID MEDIA COMPATIBILITY. A very important factor in the care and maintenance of any pressure transducer is ensuring that the transducer material is compatible with the working system fluid. Refer to paragraph 504-5.4.5. Corrosion and/or failure of the pressure transducer will definitely result from the use of an improper transducer in an unsuitable (corrosive) media.

504-5.6.2 VDC VERSUS 120 VAC. Ensure that the pressure transducer is the proper voltage type and rating for the particular application. Refer to paragraphs 504-5.4.3 and 504-5.5.3.5.

504-5.6.2.1 Deenergize the electrical circuit prior to removing or performing any maintenance on the pressure transducer. Observe all safety precautions and tag-out procedures.

504-5.6.3 GENERAL INFORMATION. Inspect the pressure transducer periodically for physical damage that would impair its operation. Generally, pressure transducers cannot be repaired in the field. If the transducer shows signs of physical damage, corrosion, or wear, replace it. The unit that was removed from service should be returned to P-72 (NWS, Yorktown) as directed by the transmitter's APL. Inspect the transducer and electrical connections for cleanliness, and ensure that they are tightened securely.

## 504-5.7 CALIBRATION

504-5.7.1 SISCAL TEAMS AND IMAs. The calibration of pressure transducers is usually performed by SISCAL Teams or IMAs.

504-5.7.2 CROSS CONTAMINATION (FLUID MEDIA). Proper measures must be observed to ensure that pressure transducers are not cross contaminated. If the transducer is used in an oxygen system it must be calibrated using approved calibration equipment and cleaned for oxygen use prior to installation in the parent system. Pressure transducers normally used in a non-corrosive media cannot be interchanged with transducers rated for corrosive systems. Refer to paragraph 504-5.4.5.

504-5.7.3 CALIBRATION EQUIPMENT. The only pressure calibrators qualified for shipboard calibration of pressure transducers are the King Nutronics model 3666 Automated Pressure Calibrator (0 - 10,000 psig) and the Datametrics model 1127-2 Low Pressure Calibrator (0 - 1,000 in H2O, 0 - 30 in Hg, 0 - 100 psig). After exercising the pressure transducer at full scale, six successive times, a calibration check is performed at a minimum of five equally spaced points covering the full pressure measurement range of the transducer. If any adjustment is required, the zero and/or span screws are adjusted to bring the transducer within the calibration specifications. The zero and span adjustments are interactive. Therefore, after any adjustment is made to either the zero or the span, the calibration must be repeated over the full range of the transducer.

## SECTION 6.

## PRESSURE/TEMPERATURE INSTRUMENT TEST AND CALIBRATION EQUIPMENT

### 504-6.1 COMPARISON METHOD PRESSURE TESTING EQUIPMENT

504-6.1.1 GENERAL. Calibration by the comparison method, as the name implies, is accomplished by comparing the gage to be tested with a master gage of known accuracy. Both stationary and portable systems are used with hydraulic or pneumatic fluids. The pressure source may be a hydraulic hand pump or a precharged gas cylinder.

504-6.1.2 MAINTENANCE. Maintenance, repair, and calibration information should be obtained from manufacturer’s manuals for the particular model.

504-6.1.3 MASTER TEST GAGES.

504-6.1.3.1 Description. Master test gages are the instruments usually employed to calibrate pressure gages by the comparison method. For shipboard use, and especially where portability is required, the test gage is the principal working standard.

504-6.1.3.2 Pressure Sensing Elements. Pressure-sensing elements of test gages are similar to those of typical shipboard gages as described in paragraph 504-3.1. They can be classified as Bourdon tube (C type, spiral, helical), bellows, diaphragm, or capsule. Although similar in design to plant or operating gages, test gages are built with much greater control of manufacturing, quality, and calibration procedures. Some major characteristics that distinguish test gages from operating gages are:

a. Accuracy of ± 0.5 percent of span, or better.

b. Increased sensitivity and repeatability as compared with less accurate and lower cost gages.

c. Dial sizes between 4-1/2 inches and 8-1/2 inches; test gages are very seldom below 4-1/2 inches in diameter. Gages are also available up to 16 inches in diameter for high precision laboratory work.

d. Instead of the common 270-degree Bourdon tube, some test gage manufacturers build gages with 300 or 360 degree tubes or with double revolution pointers. These gages, especially the latter, have enlarged scale lengths which greatly improve gage readability.

e. On many test gages there are other recognizable differences, including:
   1 A mirrored dial face for preventing parallax error in reading
   2 Approximately 12 to 20 adjustable tabs on the dial face

3 Individual setting of pressure intervals during calibration

4 Bleed tips, which permit a thorough flush with solvent when required

5 Pressure reliefs to protect gages from overpressure

504-6.1.3.3 Test Gages. Test gages can be used individually or they can be systematically grouped in various ranges and panel-mounted (with as many as 8 or 10 gages on one panel) for rapid production type testing. Some portable systems using master test gages are described in paragraphs 504-6.3.1 through 504-6.3.5.2. In these systems the test gage is combined with a portable pressure source and loading unit and used primarily for in-place testing. Master gage panels, described in paragraphs 504-6.3.4.2 and 504-6.3.4.2.1, combine regulators, valves, and associated equipment with the test gage for installation in a gage repair and calibration shop. Operating gages are brought to the panel in quantity for repair, test, and calibration. Operating gage calibration is discussed in paragraph 504-2.7.

504-6.1.3.4 Procedure. When using a master test gage for a calibration, note these factors:

a. Distinguishing physical characteristics of the test gage as described in paragraphs 504-6.1.3.1 through 504-6.1.3.3.

b. Test gage accuracy.

c. Date and place of last calibration; check for calibration sticker.

d. Type of fluid to be employed; be consistent with oil, water, or gas, and for Oxygen Clean gages use clean water-pumped nitrogen only.

e. Exercise greater care in handling test gages; their higher sensitivity causes them to be less resistant to shock.

f. In all cases check the manufacturer's instruction books, brochures, and test gage literature.

504-6.1.4 HYDROSTATIC TEST GAGES. For performing hydrostatic inspection tests of piping and non-piping systems, pressure gages provided shall include master hydrostatic test gages and backup system gages, or temporarily-installed backup gages (see **NSTM Chapter 505, Piping Systems** ).

504-6.1.4.1 Selecting Master Hydrostatic Test Gages. When selecting a hydrostatic test gage, the test gage range should be at least 1/7 greater than the test pressure but should not be more than twice that of the maximum test pressure except for test pressures below 60 psi (see Table 504-6-1). Master hydrostatic test gages and backup gages shall have an accuracy of at least +1.0 percent of gage span. In addition, master hydrostatic test gages shall have graduations equal to or smaller than those shown in Table 504-6-1. Backup gages may be installed with dial sizes of 4–1/2 inches or larger.

504-6.1.4.2 Test Pressure Accuracy Verification. Master hydrostatic test gages used to indicate actual hydrostatic test pressures shall have a valid calibration label in accordance with NAVSEA OD 45845, **Metrology Requirements List** . The backup gage shall also have a valid calibration label according to the normal maintenance requirements. In addition, the backup gage shall be cross-checked to the master hydrostatic test gage up to maximum test pressure just prior to start of testing (see note 2, Table 504-6-1).

504-6.1.5 AIR-TESTING EQUIPMENT. Air-Testing Equipment. Portable air-testing sets are supplied to those surface ships that require them for making periodic air tests of watertight compartments. There are several types of portable sets, all of which operate in a similar manner. When submarine tests are being made, see **NSTM Chapter 079 Vol. 4 (9880), Damage Control-Compartment Testing and Inspection** , for procedures.

504-6.1.5.1 Each compartment and tank on submarines shall be air-tested periodically to the pressure specified in the Schedule of Tests - Built-in Tanks and Compartments furnished each submarine by NAVSEA. Surface ship compartments, tanks, and voids also shall be air-tested periodically to the pressures specified in Schedule of Watertight Integrity Test and Inspections furnished each ship by NAVSEA.

504-6.1.5.2 Selected compartment air test measuring instruments shall have an accuracy of ±1.0 percent or better at test pressure and a sensitivity equal to or better than 1 oz/in$^2$ . Air-test gage graduations shall not be greater than 1 oz/in$^2$ .

**Table 504-6-1.** MASTER GAGE SELECTION FOR HYDROSTATIC TESTS

| System MaximumTest Pressure(lb/in$^2$ g) | | Master Gage***Range(lb/in$^2$ g) | | Master GageMaximum Graduation Size(lb/in$^2$ ) |
|---|---|---|---|---|
| **From*** | **To**** | **From** | **To** | |
| 5000 | 9500 | 0 | 10000 | 100 |
| 2500 | 4800 | 0 | 6000 | 50 |
| 1000 | 1800 | 0 | 5000 | 50 |
| 500 | 800 | 0 | 3000 | 50 |
| 250 | 400 | 0 | 2000 | 20 |
| 100 | 175 | 0 | 1500 | 20 |
| 50 | 80 | 0 | 1000 | 10 |
| 10 | 25 | 0 | 600 | 10 |
| >5 | 7 | 0 | 500 | 5 |
| | | 0 | 300 | 5 |
| | | 0 | 200 | 2 |
| | | 0 | 150 | 2 |
| | | 0 | 100 | 1 |
| | | 0 | 60 | 1 |
| | | 0 | 30 | 0.5 |
| | | 0 | 15 | 0.25 |
| | | 0 | 10 | 0.25 |

Notes

1. Master test gage and backup test gages shall track within two (2) percent of each aother.2. System maximum test pressures shall be determined by applicable overhaul specifications, building specifications, and so forth.* Values agree with the requirements that gage range shall not exceed 200 percent of test pressure except for gage ranges of 0 to 60 and lower.** Values allow for reading pressures up to relief valve settings.*** Exceptions to the values given in this table may be approved locally by design, based on an evaluation of test pressure, gage range and specific application.

504-6.1.6 PORTABLE TEMPERATURE CALIBRATORS.

504-6.1.6.1 General. Portable temperature calibrators are used to test liquid-in-glass, bimetallic and filled-system thermometers. A description of these calibrators is given in paragraph 504-6.3.5.

504-6.1.6.2 Thermocouple Simulator-Calibrator. Another type of portable temperature calibrator is the thermocouple simulator-calibrator which is used to test thermocouple measuring instruments. This particular calibrator is described in paragraph504-6.3.5.2.

## 504-6.2 SAFETY

504-6.2.1 In the operation of pressure test equipment precautions to be observed are:

1. Do not exceed the rated pressure of any gage or tester being used.
2. Do not contaminate water-actuated testers by substituting oil, or vice versa.
3. Use clean dry air or water-pumped nitrogen in low pressure pneumatic calibration systems except where pressure storage cylinders or accumulators are a part of the system. Charge these only with nitrogen.
4. Where gas storage cylinders are included, use only nitrogen or inert gas. Do not use air since an explosion hazard from diesel effect exists. Periodic cylinder inspection is required.
5. Do not interchange components between hydraulic and pneumatic calibration systems.
6. Use fluid separators as directed.
7. Handle Oxygen Clean gages and components with care. Oxygen clean gages shall be calibrated only with a certified O2 clean calibration system and by certified O2 calibration personnel. Unless the gage is being calibrated in-place, calibration shall be accomplished only after all parts have been thoroughly cleaned with inert or nonhydrocarbon solvents.
8. Use extreme caution when working with high pressure fluids, especially gas. Rupture or failure of components under high pressure could cause serious injury or death to personnel.

504-6.2.2 In the operation of the temperature calibrators (thermo units), precautions to be observed are:

1. There are no safety features in the thermo unit to prevent thermal runaway. Never leave the thermo unit unattended. If thermal runaway does occur, disconnect the power line connector from the power outlet.
2. Never attempt to move or handle the thermo unit until it has had sufficient time to cool.
3. Do not touch the chuck with bare hands or serious burns will result. Use the chuck handling tool to remove a chuck.
4. Do not touch the test instrument stem or sensing bulb when removing from the thermo unit. Serious burns may result.
5. Do not remove the chuck from the thermo unit well when the temperature exceeds 800°F.

504-6.2.3 In the operation of the thermocouple simulator-calibrator, precautions to be observed are:

1. Do not exceed the maximum rated temperature of a thermocouple.
2. Do not touch any heated parts including thermocouples or ceramic insulators until they have cooled to the ambient temperature.
3. Ensure that the calibrator thermocouple switch is set to the proper thermocouple type.

## 504-6.3 DESCRIPTION

504-6.3.1 PORTABLE PRESSURE TESTERS AND CALIBRATORS. The Navy uses several commercial models of portable pneumatic and hydraulic pressure calibrators (pressure reference standards) and pressure testers. Portable testers and calibrators are not to be used for oxygen or combustible gas testing unless specified.

504-6.3.2 CALIBRATION EQUIPMENT. Calibration equipment are devices which usually have master pressure gages or digital readouts exhibiting a tolerance (accuracy) of at least 2 times greater than the operational pressure devices being compared. An accuracy of 4 to 1 between the calibrator and the compared operational device is desirable and calibrators used by the Navy usually meet this criterion. Ship allowances for portable calibrators vary. A ship may have one or a combination of the calibrators described in paragraphs 504-6.3.3 through 504-6.3.5.2 in its allowance list, depending on the ship size and the status of the ship in the FCA program.

504-6.3.3 PNEUMATIC CALIBRATORS. Four models of pneumatic portable calibrators are described in paragraphs 504-6.3.3.1 through 504-6.3.3.5.

504-6.3.3.1 Datametrics Model 1127-2 -- Portable gage calibrator is a portable, self-contained pneumatic low pressure calibration system. The system consists of an electric or pneumatic vacuum/pressure pump with hoses, filters, and adapters and a pressure control unit that includes the electronics/digital display/pressure control subsystems. The calibrator should be used with fluid separators when required. The 1127-2 has usable calibration ranges of 0 to 30 in. Hg and 0 to 30 in. Hg Vac., 0 to 400 in. $H_2$ O to 1000 in. $H_2$ O (or 100 kPa), and 0 to 100 lb/in$^2$ g. This calibrator is designed to perform in-place or on-site calibration of both pneumatic and hydraulic pressure instruments with tolerances up to and including ±0.5 percent of full scale. The combined gross weight of the control unit and the pump unit is approximately 68 pounds.

504-6.3.3.2 King Nutronics Inc. Model 3657-1-1--Portable Pressure Calibrator is part of the King Nutronics Model 3657 system. This five-case unit is a portable, self-contained hydraulic Pressure calibration system consisting of a hydraulic (water-filled) hand pump subassembly with manifold and test gage adapter kit, six master gages, fluid separators, hoses, and fluid bottles. This calibrator has a usable calibration range of 5 to 10,000 lb/in$^2$ g and is designed to perform primarily in-place or on-site calibration of hydraulic pressure instruments and on-site calibration of pneumatic pressure instruments with tolerances up to and including ±0.5 percent of full scale. The approximate combined weight of these units is 150 pounds.

504-6.3.3.3 King Nutronics Inc. Model 3666-10K-1--Portable Automated Pressure Calibrator is a portable automated high pressure instrument calibrator for shipboard pressure instrument calibration and maintenance. Ranges of calibration pressures are 1.5 to 10,000 lb/in$^2$ g and 15 to 2500 lb/in$^2$ absolute with a digital display unit capable of providing readings in lb/in$^2$ g, lb/in$^2$ a, inches of fresh water, feet of fresh water, feet of seawater, and inches and millimeters of mercury. Accuracy of gage pressure readings vary from 0.1 percent of full scale from 1.5 to 20 lb/in$^2$ g to + 0.1 percent of indicated value from 20 to 10,000 lb/in$^2$ g. Accuracy of absolute pressure reading is ± 0.03 lb/in$^2$ a from 10 to 18 plus the accuracy values obtained for lb/in$^2$ g over the atmospheric pressure value. The calibrator consists of five separate interconnecting units:

1. The pressure controller and digital pressure readout with remote hand-held terminal; the main pressure controller unit requires a power source of 115 Vac, 60 Hz, and 1725 watts capacity.
2. The high pressure module (1000 to 10,000 lb/in$^2$ g).

3. The accessory case, which contains two fluid separators, (water and oil), interconnecting pressure hoses, and test gage adapter and packing kits.
4. The portable nitrogen supply assembly, which consists of a nitrogen supply cylinder and manifold assembly. The nitrogen cylinder is similar to LUXFER. USA Limited Model IN60 aluminum cylinder.
5. The test and maintenance panel, which consists of a self-diagnostic programmed test system.

504-6.3.3.4 The approximate combined weight of these units is 140 pounds.

504-6.3.3.5 King Nutronics Inc. Model 3461-1-104--Pressure Calibrator is a portable oxygen gage clean pressure calibration system consisting of a pneumatic pressure control unit, nitrogen supply bottle, hoses, adapters, and six gages, covering a range of 0 to 10,000 lb/in$^2$ with an accuracy of ±0.1 percent of full scale. This calibrator may be used only by personnel trained and certified to calibrate instrumentation. The control unit, gage and accessory case assembly, and the portable supply cylinder have an approximate combined weight of 145 pounds.

504-6.3.4 STATIONARY TEST EQUIPMENT. This equipment is generally arranged as panel-mounted or bench-mounted systems located in calibration laboratories or gage repair shops. This equipment is used on a limited basis in tender shops.

504-6.3.4.1 General. Operating gages are mounted for test on a stand or manifold connected (usually with flexible quick-disconnect hose) to a master test gage panel. The panel is connected, in turn, to a pressure source. In addition to test manifolds, a pressure chamber may be used to test environmental units such as caisson gages. Where vacuum gages must be calibrated, a vacuum pump and chamber are employed. For some low pressures, manometers are used as master indicators. The major components of stationary systems are described in detail in paragraphs 504-6.3.4.2 through 504-6.3.4.3.7.

504-6.3.4.2 Master Gage Panels. Several master test gages may be grouped on one panel according to pressure range and calibrating medium; for example, panels for Tender and Repair Ship MIRCS are designated as:

1. Low Pressure Air and Automatic Control
2. Hydraulic (Water) 0 to 10,000 lb/in$^2$
3. Low and Medium Pressure Nitrogen (Oxygen Clean)
4. High Pressure Nitrogen (Oxygen Clean)

504-6.3.4.2.1 The pressure source provided for the panel may be either a shipboard nitrogen or clean air supply, a bottled nitrogen supply, a high pressure nitrogen booster, or a water pump.

504-6.3.4.2.2 Pumps and Boosters. Three particular pumps and boosters selected for shipboard used are described in paragraphs 504-6.3.4.2.2.1 through 504-6.3.4.2.2.3. Other styles and types may be found, but the basic principles will apply.

504-6.3.4.2.2.1 The hand-operated hydraulic (water) pump is a piston pump made by Pressure Products Industries, Inc., consisting of a reservoir, primer, piston assembly, gage, pressure relief, and various valves.

504-6.3.4.2.2.2 The air-driven hydraulic (water) pump is a double-acting high pressure pump manufactured by Combination Pump Valve Company and consisting of an air motor, transfer valve, two pump heads, a reservoir, an air regulator filter-lubricator unit, an accumulator, and various valves. The driving unit of the pump is the air-operated motor which has a double-acting piston with a transfer valve controlling piston movement. Each pump head contains a high pressure piston and two check valves controlling the flow of low pressure and high pressure liquid. The air regulator controls ship air used to operate the pump.

504-6.3.4.2.2.3 The air-driven nitrogen booster is a completely piped and self-contained unit consisting of a gas boost compressor, a 20-in$^3$ accumulator, and all necessary gages, valves, and accessories. The unit is manufactured by Pressure Products Industries, Inc. From a suction pressure range of 800 lb/in$^2$ g minimum to 2300 lb/in$^2$ g maximum, the booster is capable of obtaining an outlet pressure of 10,000 lb/in$^2$ g.

504-6.3.4.2.3 The unit is deck mounted and enclosed in a steel cabinet about 25 inches square with top and bottom access. It is manufactured and should be maintained under Oxygen Clean conditions; that is, free from oil, grease, and other organic substances, and free from all loose scale, rust, filings, and other foreign material.

504-6.3.4.3 Vacuum and Pressure Chambers. Various vacuum and pressure chambers are in use throughout the Navy. Two used in the MIRCS Program are described in paragraphs 504-6.3.4.3.1 through 504-6.3.4.3.7.

504-6.3.4.3.1 The vacuum and low pressure chamber made by Ideal Aerosmith Division of Royal Industries, Inc., is used in conjunction with the low pressure pneumatic test bench and as such is connected with a vacuum pump, a 0 to 30-inch mercury panel-mounted master vacuum gage, a 1 to 1000 microns electronic vacuum gage, and 0 to 50-inch mercury and water manometers.

504-6.3.4.3.2 The vacuum and low pressure chambers is designed for test and calibration of altimeters, pressure transducers, and so forth. Range is about 5 microns vacuum to 50 lb/in$^2$ g. Inside dimensions are 10-1/2-inches wide by 5-1/2-inches high by 12-inches deep with access by a front, quick-latching plastic-windowed door.

504-6.3.4.3.3 The pressure chamber (0 to 1000 lb/in$^2$ g) is a cylindrical, bench-mounted chamber with associated piping, valves, pressure regulators, and master gages. It is designed for environmental pressure testing of gages such as caissons and differential caisson types with nitrogen to 1000 lb/in$^2$ g maximum. It is manufactured by Pressure Products Industries, Inc. Inside dimensions of the chamber are 9 inches minimum diameter by 14 inches long with access by a breech-lock quick-opening door. A 4-inch sighting port is installed on the door. The pressure seal is a Buna N-ring with brackets; it is important that the sealing surface of the vessel and the ring be kept in excellent condition for the seal to work satisfactorily at all times. The chamber is opened by rotating a breech nut until lugs on the door are clear and the cover can be pulled out and rotated away from the chamber. Accidental opening of the door while the unit is pressurized is prevented by a safety pneumatic interlocking device.

504-6.3.4.3.4 One pressure tap provides chamber pressure and another provides an independent pressure for the threaded side of differential caisson gages.

504-6.3.4.3.5 The chamber may also be employed a a vacuum chamber by connecting a vacuum pump at the fitting provided and using an appropriate master gage.

504-6.3.4.3.6 Miscellaneous Apparatus. Fifty-inch U-tube manometers are used as masters in conjunction with the low pressure air and automatic control panel. A complete discussion on manometers is given in Section 7.

504-6.3.4.3.7 Several pieces of equipment described in this section are equipped with rupture assemblies or pressure fuses. Replacement discs should be perfectly flat and contain no bends, crimps, scratches, or other flaws.

504-6.3.5 PORTABLE TEMPERATURE CALIBRATORS. The Navy uses two commercial models of portable temperature calibrators (thermo units).

504-6.3.5.1 King Nutronic Inc. Model 3604 & 3605 -- Thermo Units are portable, self-contained temperature test systems incorporating a dry well heat or cold source, digital circuitry, and adapter chucks for calibrating a variety of temperature measuring instruments in the range of -40° to 250°F (3605) and 100° to 1200°F (3604). The thermo unit consists of a chassis assembly installed in a carrying case. A rack provides storage for up to 12 adapter chucks. The temperature well permits direct insertion of an item (with a stem at least 4 inches in length) under test through doors which close around the test item. Temperature in the well is controlled by thermoelectric modules and sensed by a resistance thermometer. The temperature is displayed on the top panel indicator in degrees Fahrenheit or Celsius. The thermo units can calibrate instruments with accuracies up to and including ±1 percent of range span or ±1.5 degrees, whichever is greater.

504-6.3.5.2 Ectron Corp. Model 1100 CF -- Thermocouple Simulator-Calibrator is a portable, self-contained test system for calibrating thermocouple measuring instruments. This unit can be used to simulate or calibrate Type E, J, K and T thermocouples. The selected thermocouple material terminals provide easy connection, and the corresponding temperature values can be read directly in degrees Fahrenheit or Celsius. The calibrator can also be used as a precision millivolt source. The unit contains a null-meter for use in the differential temperature measurement mode. The unit can calibrate thermocouple measuring type instruments in the range of 0 to 2500 degrees Fahrenheit.

## 504-6.4 OPERATION

504-6.4.1 GENERAL. The following paragraphs discuss the operation of the portable pressure and temperature calibrators contained in this section. The applicable Naval technical manual, or manufacturer's manual, should be referred to for detailed step-by-step operating instructions and safety precautions.

504-6.4.2 DATAMETRICS MODEL 1127–2 PORTABLE GAGE CALIBRATOR. The calibration of pressure or vacuum instruments using the calibrator consists of connecting the pump unit and the control unit together via the interconnecting supply hose. Pneumatic and hydraulic instruments are connected to the filter reservoir assembly part of the pump unit, which in turn is connected to the TEST PORT of the control unit using the appropriate hoses. The control unit controls are then adjusted for the specified pressure or vacuum indications on the test gage. These indications are compared to the pressure or vacuum displayed on the control unit's digital panel meter.

504-6.4.2.1 All pressure gages will be calibrated pneumatically unless, for a practical reason, a hydraulic pressure gage cannot be evacuated. The filter-reservoir assembly shall be used when calibrating any pressure gage.

504-6.4.2.2 The pump unit is the source of pressure and vacuum. The pump provides 102 psi of air pressure at the PRESSURE port and 28 inches of mercury vacuum at the VACUUM port. Connect the output on the pump unit, either vacuum or pressure as required, to the PRESSURE/VACUUM SUPPLY PORT on the control unit via the interconnecting hose. Connect a pneumatic or hydraulic test gage to the OUTPUT PORT on the filter reservoir assembly using a hydraulic test hose. Then connect the INPUT PORT of the filter reservoir assembly to the TEST PORT on the control unit via an interconnecting hose. Control the test pressure by turning on the pump, closing both the VENT CONTROL valve and RAPID VENT valve and slowly opening the PRESSURE/ VACUUM CONTROL valve. This increases the pressure/vacuum in the test pressure/vacuum manifold which consists of all the calibrator components and plumbing between the PRESSURE/VACUUM CONTROL valve and the test gage. The increase in pressure/vacuum will be indicated by both the digital panel meter and test gage.

504-6.4.2.3 Before starting the calibration of a test gage, the calibrator must be exercised. This is accomplished with the test hose removed from the TEST PORT and is fully described in the appropriate MRC or Instrument Calibration Procedure (ICP).

504-6.4.2.4 Zero the digital panel meter by first closing the PRESSURE/VACUUM CONTROL valve and opening the RAPID VENT valve. Allow the system to stabilize for at least ten seconds, then use the ZERO control potentiometer to set the digital panel meter to indicate exactly ″00000″. Adjust the digital panel meter for a full scale by setting the RANGE switch to the range required. Then depress the FULL SCALE CHECK switch and use the FULL SCALE ADJUST to set the digital panel meter indication for the full scale indication of the range selected. The system is now ready to calibrate either pressure or vacuum gages, depending upon the setting of the PRESSURE/VACUUM SELECTOR valve and the supply connection on the pump unit.

504-6.4.2.5 Mount the test gage for calibration in the same position it is mounted in the pressure system. The majority of pressure gages are mounted vertically. If a special mounting position is not indicated on the gage, test it vertically. The calibrator can be used in either the vertical or horizontal position. Calibrate the test gage at four points representing 25, 50, 75 and 100 percent of full scale range. The calibration is performed by providing the four test pressure values in an increasing order, then in a decreasing order. At each setting, the test gage indication is compared to the calibrator digital panel meter indication.

504-6.4.2.6 Upon completion, set the pump POWER switch to OFF. Open the RAPID VENT and PRESSURE/VACUUM CONTROL valves to bring the system to atmospheric pressure. Disconnect and secure the equipment.

504-6.4.3 KING NUTRONICS INC. MODEL 3657–1–1–1 PORTABLE PRESSURE CALIBRATOR. The hand pump case assembly should be situated within ten feet of the test gage isolation valve, if applicable. Do not operate the hand pump unless it has been filled and primed. Loosen the FILL-VENT plug 1/2 to 3/4 turn. Pull the range selector valve to the high volume, low pressure position. Open the hand pump vent valve.

504-6.4.3.1 Select the lowest range master gage that will cover the test gage pressure range. Install the selected master gage in one of the hand pump manifold sockets.

504-6.4.3.2 Connect the calibrator test hose to the test gage isolation valve test port using the appropriate adapter. Connect the other end of the test hose to the unused hand pump manifold socket. If a fluid separator is used, ensure that it has been filled and connect it to the probe adapter at the isolation valve test port. Attach the test hose to the unused hand pump manifold socket. Close the vent valve.

504-6.4.3.3 Calibrate the test gage at four points representing 25, 50, 75 and 100 percent of full scale range. The calibration is performed by providing the test pressure values in an increasing order, then in a decreasing order. At each setting, the test gage indication is compared to the master gage indication.

504-6.4.3.4 Operate the hand pump slowly to obtain each of the calibration test points. For the decreasing order tests, open the vent valve slowly to obtain each of the test points. Upon completion of the tests open the vent valve fully to bleed any pressure, then close and tighten the FILL-VENT plug. Disconnect and secure the equipment.

504-6.4.4 KING NUTRONICS INC. MODEL 3666–10K-1 PORTABLE AUTOMATED PRESSURE CALIBRATOR (APC). The APC pressure control unit should be situated within ten feet of the isolation valve so the high pressure test hose and the remote control will reach. If the test gage is to be removed for calibration, the ten-foot distance does not apply. Access to 115 V, 50-60 Hz power is necessary.

504-6.4.4.1 Locate the pressure intensifier within five feet of the control unit, and the nitrogen supply within five feet of the intensifier. Connect the pressure intensifier DISCHARGE port to the control unit SUPPLY port with the jumper hose, and connect the nitrogen supply to the intensifier SUPPLY port with the supply hose. Set the intensifier PRESSURE ADJUST switch to 1,000 psig, if applicable. Secure the nitrogen supply to a stable structure with the nylon strap. Connect the intensifier and the control unit to a 115V, 50-60 Hz power source.

504-6.4.4.2 Ensure the control unit EMERGENCY VENT valve is closed (knob up), and that the VENT valve is also closed. Unscrew (2 turns) the FILL-VENT plug to provide venting to the hydraulic reservoir.

504-6.4.4.3 A liquid trap assembly should always be used when performing calibrations. Be sure to fill the fluid separator completely when working with oil. If there are any bubbles in the fluid separator or lines, a combustible mixture may form and be ignited under pressure. If hydraulic gages are to be calibrated, a supply of the applicable fluid should be on hand for filling the fluid separator.

504-6.4.4.4 If the remote terminal is to be used, remove it from the control unit cover and connect it into the control unit REMOTE connector.

504-6.4.4.5 Unless a vacuum is being connected, leave the dust plug in the control unit VACUUM port.

504-6.4.4.6 The following sequence of events illustrates the operation of the APC in calibrating a pneumatic gage. This example was selected to illustrate the various programmed functions related to the calibration of pressure gages and transducers. Also assumed is the requirement for a permanent printed record. Whenever the displayed message starts with ″ENTER″, key in the required information and press ENTER.

**Table 504-6-2.** PRESSURE GAGE CALIBRATION SAMPLE COMMANDS & RESPONSES

| Operator Action | Display Response | Printer Response |
|---|---|---|
| 1. POWER on | ELECTRONICS SELF TESTRevision 3.4-10K | - - |
| 2. - - | ELECTRONICS OK PUSH ADV | - - |

**Table 504-6-2.** PRESSURE GAGE CALIBRATION SAMPLE COMMANDS & RESPONSES - Continued

| Operator Action | Display Response | Printer Response |
|---|---|---|
| 3. Touch ADV | INSTALL LIQUID TRAP AT TEST PORT PUSH ADV | - - |
| 4. Touch ADV | PRINTER DESIRED?1 - YES 2 = NO | - - |
| 5. Touch 1 | ENTER DATE-MONTH/DAY/YEAR | - - |
| 6. Enter date (Ex: 11/19/96) | 111996 | |
| 7. Touch ENTER | ENTER GAGE S/N IF ANY | ***START OF TEST***DATE XX/XX/XX |
| 8. Enter No. | 1 2 3 4 | S/N 1 2 3 4 |
| 9. Touch ENTER | 1 = GAGE or TRANSDUCER,2 = SWITCH | |
| 10. Touch 1 | 1 = PRESS 2 = VAC 3 = ABS | |
| 11. Touch 1 | 1 = GAS 2 = LIQUID | PRESSURE GAGE |
| 12. Touch 1 | CONNECT AGE PUSH ADV | |
| 13. Connect gage | ENTER FULL SCALE VALUE: | |
| 14. Touch (Numbers) | ENTER FULL SCALE VALUE: | PRESSURE GAGE FULLS CALE PSI GAGE |
| 15. Touch ENTER | UNITS PSI YES = ADVNO = CLR | |
| 16. Touch ADV | ENTER TOLERANCE %: | |
| 17. Touch NUMBER | ENTER TOLERANCE %: | |
| 18. Touch ENTER | TEST POINTS1 = AUTOMATIC2 = MANUAL ENTRY | TOLERANCE %: |
| 19. Touch 1 | DOWN SCALE TEST DESIRED?1 - YES 2 = NO | |
| 20. Touch 1 | 1 = NORMAL CALPRINTER DESIRED:1 - YES 2 = NO2 = RESTRICTED-CAL LAB ONLY | |
| 21. Touch 1 | ***SYSTEM VENTING***(after 10 seconds)FIRST POINT XXXX PUSH ADV | |
| 22. Touch ADV | APPROACHING XXX.XXPSI - - - ACTUAL XXX.XX | |
| 23. - - | MANUAL SET XXX.XXPSI - - - ACTUAL XX.XX | |
| 24. Touch INCREASE | MANUAL SET XXX.XXPSI - - - ACTUAL XXX.XX | |

**Table 504-6-2.** PRESSURE GAGE CALIBRATION SAMPLE COMMANDS & RESPONSES - Continued

| Operator Action | Display Response | Printer Response |
|---|---|---|
| 25. Touch MEAS | PASS/FAIL XXX.XXACTUAL XXX.XX | AGE READSXXX.XXTRUE PRESS XXX.XXDEVIATION .XXX% DEV:PASS/ FAIL.XXX% |
| 26. Touch ADV | Continue Cal points up to high limit, then repeat down scale to first test point | Prints as in step 24 for all test pointsup and down scale |
| 27. | ***SYSTEM VENTING*** COMPLETE 1 = IDENTICAL2 = NEW TEST | |

504-6.4.4.7 At completion of testing/calibration operation turn off pressure at the nitrogen supply cylinder, set POWER switch to the OFF position, open VENT valve and close FILL-VENT plug. After pressure line has been completely vented, vent supply pressure hose at the nitrogen supply cylinder and remove high pressure hoses and replace dust plugs.

504-6.4.5 KING NUTRONICS INC. MODEL 3461–1–104 PORTABLE PRESSURE CALIBRATOR. The operating instructions that follow are provided only as a guide to illustrate the use of the calibrator. The calibrator should be situated as close as possible to the test gage isolation valve. Connect the nitrogen source to the calibrator control unit.

504-6.4.5.1 Select the master gage that covers the test gage scale pressure range. Exercise the master gage in accordance with the manufacturer’s instructions and/or the applicable calibration procedure.

504-6.4.5.2 The test gage is then isolated from its normal system pressure using the isolation valve. A high pressure test hose is then used to connect the test port of the isolation valve to the portable calibrator control unit.

504-6.4.5.3 Pressure is now applied to the test gage in an increasing order, by use of the control unit. First equalize the pressure on both sides of the vernier control valve piston by setting the equalizing valve in the balance position. Pressure is applied slowly until the first test point is reached. For fine adjustment turn the vernier equalizing valve to the isolate position. The vernier control valve should now be used to adjust to the final pressure setting. When this pressure is indicated on the test gage, the master gage is tapped lightly and read. The master gage indication is compared to the test gage indication to determine if the test gage is within the specified tolerance limits. Additional pressure is now applied to reach the next test point. This procedure is followed until the highest test point has been reached.

504-6.4.5.4 The test gage is now calibrated in a decreasing pressure order. The calibrator vent valve is used to slowly vent off the pressure, and obtain each test point. The vernier control valve is used as described above except for decreasing pressure. In each case, the master gage is tapped lightly and read, then compared to the test gage indication.

504-6.4.5.5 Upon completion of the tests the vent control valve should be fully opened to bleed off any remaining pressure. Disconnect and secure the equipment.

# SECTION 7.

# MANOMETERS AND DRAFT GAGES

## 504-7.1 MANOMETERS

504-7.1.1 DESCRIPTION. The manometer is a simple, direct pressure measuring instrument in which the measured pressure is balanced by the weight of a fluid column. Since the density and height of the liquid column can be determined with high precision, the manometer is considered to be one of the most accurate of all pressure measuring instruments. In its various forms, the manometer is used to measure such pressures as gage, differential, atmospheric and absolute.

## 504-7.2 SAFETY

504-7.2.1 All of the manometer fluids used other than colored water are health hazardous materials and should be handled in accordance with Material Safety Data Sheets requirements and **NSTM Chapter 670, Stowage Handling, and Disposal of Hazardous General Use Consumables** .

## 504-7.3 APPLICATIONS

504-7.3.1 Manometers have been removed/eliminated from most ships but may still be found in shipboard or shore based calibration laboratories.

## 504-7.4 TYPES

504-7.4.1 The three basic types of manometers used are the U-tube, well type and inclined tube type. As the name implies, a U-tube manometer has a single glass tube formed in a U shape. The scale is marked in equal increments above and below a zero point. Pressure is applied to one leg which drives the fluid down in one leg and up in the other. The measured pressure is determined by adding the indications above and below the zero mark. In well type manometers a single tube is connected to a well containing the indicating fluid. Pressure is applied to the well which causes the fluid to rise in the indicating tube. The top of the tube is normally open to the atmosphere. The measured pressure is read directly from the indicating scale mounted alongside the manometer tube. The inclined manometer is another form of a well type manometer, the vertical tube is inclined at an angle which greatly expands the range over a much longer scale length. This provides much smaller increments of pressure measurement capability.

## 504-7.5 OPERATION

504-7.5.1 The interaction of an indicating liquid with the tube walls due to surface tension causes the liquid to deflect and assume a curved surface called the meniscus. Liquids which wet the tube, such as water and oil, have a concave (downward curve) meniscus. Mercury, which does not wet the tube, has a convex (upward curve) meniscus. The smaller the tube bore, the greater the deflection. This phenomenon in small bore tubes is called ″capillary action″. When taking a reading on a manometer containing oil or water the pressure is determined by reading the scale mark corresponding to the bottom of the meniscus, for a manometer containing mercury the scale is read at the top of the meniscus.

## 504-7.6 CALIBRATION

504-7.6.1 The U-tube manometer, when made with a uniform large bore tubing and filled with pure water or mercury, can be considered as a primary standard instrument since its standardization involves only length measurements, and temperature, capillary and gravity corrections. Secondary manometers may be calibrated against a primary standard manometer or by comparison with a low range deadweight gage tester.

## 504-7.7 BOILER DRAFT GAGES

504-7.7.1 DESCRIPTION. The U-tube manometer, when made with a uniform large bore tubing and filled with pure water or mercury, can be considered as a primary standard instrument since its standardization involves only length measurements, and temperature, capillary and gravity corrections. Secondary manometers may be calibrated against a primary standard manometer or by comparison with a low range deadweight gage tester.

## 504-7.8 TYPES

504-7.8.1 The vertical scale type draft gage is the common type used aboard naval ships. In the vertical scale type draft gage the actuating mechanism between the pointer and the diaphragm is arranged so the pointer moves in a vertical plane. There are four classes of this type of instrument.

a. Class 1. Single unit with one indicating scale.

b. Class 2. Dual unit with a low range and high range scale.

c. Class 3. Triple unit with a low, medium, and high range scale.

d. Class 4. Multiple unit with not more than four scales consisting of either four class 1 units or two class 2 units.

## 504-7.9 ACCURACY

504-7.9.1 The accuracy of the vertical scale type gage is within #2 percent of total scale range. Figure 504-7-1 shows a typical vertical scale type draft gage.

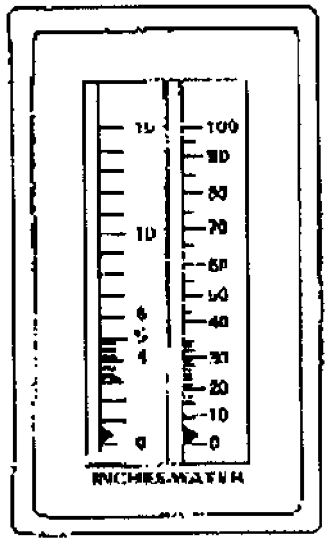


Figure 504-7-1. Vertical Scale Type Draft Gage

## 504-7.10 CALIBRATION

504-7.10.1 Zero adjustment and calibration of draft gages should only be accomplished by FCA personnel using a secondary standard manometer or deadweight gage.

## SECTION 8.
## BAROMETERS

### 504-8.1 ENGINEERING PRINCIPLES

504-8.1.1 GENERAL. The barometer is an absolute pressure device used to measure atmospheric pressure. Two types are used in the Navy, the mercurial and the aneroid. The simpler is the mercurial which, in its basic form, consists of a long glass tube sealed at one end and filled with mercury. The bottom end of the glass tube is attached to a mercury well (cistern) which is open to atmospheric pressure. The pressure in the glass tube above the mercury column is evacuated to zero pressure; thus the only pressure on the system is the atmospheric pressure acting on the cistern. This causes the mercury to rise in the tube until the pressure generated by the mercury column is equal to the atmospheric pressure. As shown in Figure 504-12-2, barometric pressure is indicated by the height of mercury in the tube above the level in the cistern.

504-8.1.2 EVACUATED PRESSURE CAPSULE. The aneroid barometer consists of an evacuated pressure capsule, mounted in a case housing, linked to a pointer which indicates the atmospheric pressure directly on a dial scale.

504-8.1.3 PRESSURE UNITS. Atmospheric pressure is measured and indicated in inches of mercury (in Hg) or millibars (mb). One millibar is equal to a force of 1000 dynes over an area of 1 cm2. The average atmospheric pressure of 29.92 inches of mercury is equal to 1013.3 millibars.

## 504-8.2 DEFINITIONS

504-8.2.1 MERCURIAL BAROMETER. A barometer that uses the height of a column of mercury in a glass tube to measure atmospheric pressure.

504-8.2.2 ANEROID BAROMETER. A barometer that uses an evacuated pressure capsule in conjunction with a pointer mechanism to measure atmospheric pressure.

## 504-8.3 SAFETY

504-8.3.1 Mercurial barometers have been removed from most ships as mercury is a health hazardous substance. Avoid continued breathing of mercury vapors. Use, handling, and storage of mercury shall comply with **NSTM Chapter 670, Stowage, Handling, and Disposal of Hazardous General Use Consumables** .

## 504-8.4 ANEROID BAROMETERS

504-8.4.1 DESCRIPTION. The Navy uses marine aneroid barometers manufactured by several companies. The principle part of these instruments is the evacuated pressure capsule or cell. This is most commonly a diaphragm assembly - a flexible walled, sealed, metal chamber containing a partial vacuum.

504-8.4.2 One wall of the chamber is secured to the frame of the instrument. The free wall of the chamber is connected to the indicator or pointer by a combination of levers, sector racks, pinions, pivots, or linkage chains. Any change in the atmospheric pressure compresses the chamber. When the atmospheric pressure decreases, the chamber expands. The diaphragm wall actuation of the lever system will then move the indicator hand and the atmospheric pressure can be read directly on the dial. The dial face is graduated in inches of mercury and millibars on concentric scales. The pressure measurement range of the instrument is from 26.5 to 31.5 inches of mercury. In addition to the indicator hand, a set hand is provided which can be moved by a knob on the case front.

504-8.4.3 The instrument is housed in a metal, crystal-front gage case suitabale fo rbulkhead mounting. A zero adjust screw (labeled REGULATOR) is accessible through an opening in the case. In addition, air ipasses to the outside of the diaphragm through this opening.

504-8.4.4 One method of temperature compensation for barometers is by use of a bimetallic arm connected to the indicator movement. Deflection of the arm due to temperature change modifies the action of the indicator movement.

504-8.4.5 Although not usually found aboard ship the barograph is a notable variation of the aneroid barometer. It is essentially a recording barometer. A pen actuated by the aneroid movement rests against a cylinder rotated at a uniform speed by a clock mechanism. The atmospheric pressure fluctuations are recorded on a chart fastened to the cylinder.

## 504-8.5 OPERATION

504-8.5.1 READING. The manufacturer sets the ″zero adjust″ on the aneroid barometer by comparisons to a standard mercurial barometer at atmospheric pressure. The aneroid barometer will then indicate the local atmospheric pressure correctly at any elevation within its range. If it is not practical to move the barometer, the reading for any elevation may be calculated. The barometer is read at a convenient location and a correction factor is applied for the difference in altitude. The barometer reading will be lowered by about 0. 034 millibars for each foot that it is elevated.

504-8.5.1.1 Whatever the elevation, the surrounding atmospheric pressure will apply an opposing force to the internal pressure in the aneroid barometer capsules. As the atmospheric pressure changes, the external opposing force on the capsules also changes. This results in a change in the deformation of the capsules which is transmitted to the free end of the top capsule. This displacement is transferred through the lever arm to the sector gear. The sector gear in turn rotates the pinion which moves the pointer. Thus, very small changes in atmospheric pressure are magnified and displayed on the dial of the barometer.

504-8.5.2 TEMPERATURE COMPENSATION. The components of an aneroid barometer are affected by temperature in different amounts, depending on the composition of the material. The following two methods, separately or in combination, are used to overcome the effects of temperature:

a. A small amount of inert gas is left in the aneroid capsule just as it is sealed; and/or

b. An additional temperature compensation device is introduced elsewhere in the mechanism (see paragraph 504-8.4.3).

504-8.5.2.1 The reference temperature for the aneroid barometer ML-448/UM 6685-00-600-3777 is 70°F. Its maximum error due to temperature effects is + 0. 015 millibars per each 1°F difference between reference and ambient temperature. The reference temperature for the General Barometer 6685-00-290-4034 is 73°F, with a maximum error of ± 0.034 millibars per °F. The reference temperature for the aneroid barometer FA-112 6685-00-847-1947 is 75°F, with a maximum error of ± 0.004 millibars per °F.

## 504-8.6 CARE AND MAINTENANCE

504-8.6.1 HANDLING. Although the aneroid barometer is readily portable and rugged in construction, it is a precision instrument and should be handled carefully when moved.

504-8.6.2 MAINTENANCE AND REPAIR. The aneroid barometer is virtually maintenance free. Repairs should only be performed by an experienced calibration technician. Detailed instructions for disassembly and repair may be found in the manufacturer's manuals.

504-8.6.3 TROUBLE DIAGNOSIS. Suggestions for diagnosing trouble when an aneroid barometer is suspected of malfunctioning are:

a. If readings are inaccurate over a given range, the barometer requires calibration - the speed of the movement must be set so the pointer will respond to pressure changes at the proper rate.

b. If the pointer does not move, the diaphragm chamber may be leaking, the lever system may be sticking or binding, or the lever system may be loose.

### 504-8.7 CALIBRATION

504-8.7.1 CALIBRATION INTERVALS. Calibration intervals are assigned in accordance with NAVSEA's Metrology and Calibration Program and the Field Calibration Activity Metrology Requirements List. Common calibration intervals range from six to thirty-six months. Should problems occur with the barometer, repair and calibration may be required before the assigned calibration interval has expired.

504-8.7.2 METHOD AND EQUIPMENT. These instruments can be calibrated using the King Nutronics 3671A Aneroid Barometer Calibration System (ABCS). The ABCS can calibrate aneroid barometers in the range of 13 to 35 in Hg (450 to 1180 mb) with an accuracy of + 0.002 in Hg.

504-8.7.2.1 These instruments can be calibrated using the King Nutronics 3671A Aneroid Barometer Calibration System (ABCS). The ABCS can calibrate aneroid barometers in the range of 13 to 35 in Hg (450 to 1180 mb) with an accuracy of + 0.002 in Hg.

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## SECTION 9.

## TANK LEVEL INDICATORS

### 504-9.1 ENGINEERING PRINCIPLES

504-9.1.1 Liquid level may be measured directly by using the varying liquid level as a means of obtaining a measurement, or indirectly, by using a variable which changes with liquid level to actuate a measuring mechanism. Sounding rules, gaging tapes, and float gages are direct reading devices. Static head indicators, electrical indicators, and differential pressure gages are indirect reading devices. Float-actuated indicators can be direct reading (float gage) or indirect reading (magnetic float), depending on the configuration and application. Usually, level is sensed in the tank at either an air-liquid interface or liquid-liquid interface. Tank level measurement is used to determine how much of a given liquid has been removed from or remains in a tank. Hence, the linear tank level measurement must be related to the geometric configuration of the tank. In rectangular shaped tanks, level and volume are linearly related. In odd-shaped tanks, by far the most common, volume must be determined at given increments as a function of level. Therefore, initial calibration of tank capacity gages or development of capacity tables and curves depends upon tank geometry. Common units of tank capacity and their conversions are as shown in Table 504-9-1.

**Table 504-9-1.** COMMON UNITS OF TANK CAPACITY AND CONVERSIONS

| Unit of Tank Capacity | Conversion |
|---|---|
| 1 gallon freshwater1 cubic foot freshwater1 cubic foot freshwater1 cubic foot seawater | 0.1337 cubic feet7.48 gallons62.43 pounds64.0 pounds |

## 504-9.2 DEFINITIONS

504-9.2.1 SOUNDING. The measurement of liquid depth.

504-9.2.2 DIRECT READING DEVICE. A direct reading device is an instrument that measures liquid level directly. Three types of direct reading devices are sounding rules, gaging tapes, and float gages.

504-9.2.3 INDIRECT READING DEVICE. An indirect reading device is an instrument that measures liquid level indirectly by using a variable that changes with liquid level (such as pressure) to actuate a measuring mechanism. Three types of indirect reading devices are static head indicators, electrical indicators, and differential pressure gages.

504-9.2.4 CAPACITY CURVE. A capacity curve is a graphic plot of the linear level of liquid in a tank versus the corresponding volume of liquid in the tank. Capacity curves (or capacity tables, discussed below) are used to convert a linear liquid level measurement, obtained from a direct reading device, to a liquid volume. Capacity curves are developed during tank construction.

504-9.2.5 CAPACITY TABLE. A capacity table is a table of the linear level of liquid in a tank versus the corresponding volume of liquid in the tank. Capacity tables (or capacity curves, discussed above) are used to convert a linear liquid level measurement, obtained from a direct reading device, to a liquid volume. Capacity tables are developed during tank construction.

## 504-9.3 SAFETY

504-9.3.1 TOXIC INDICATING LIQUIDS. Toxic indicating liquids shall not be used on potable water tanks.

**WARNING**

**Manometer indicators containing red-colored acetylene petrobromide as the indicating liquid shall not be used on potable water tanks. Acetylene petrobromide is toxic when ingested, posing a health hazard. Any potential for contamination shall be eliminated wherever this system is installed.**

504-9.3.2 TANK ENTRY. When maintenance to tank level indicators requires tank entry, the tank must be vented, cleaned, and inspected prior to entry. This procedure is discussed in **NSTM Chapter 074, Volume 1, Welding and Allied Processes** , HOT WORK IN WAY OF FLAMMABLE OR EXPLOSIVE MATERIALS AND ENTRY INTO CLOSED OR POORLY VENTILATED SPACES.

504-9.3.3 TANK TOP PRESSURE. Tank top pressure measuring systems are used to measure the tank top pressure that is developed during fueling or ballasting of compensated fuel tanks. The pressure must be monitored to prevent tank over-pressure and possible structural damage. Tank over-pressure is possible if the filling rate and pressure are greater than that which the overboard discharge can accommodate.

## 504-9.4 DESCRIPTION AND OPERATION

504-9.4.1 ACCURACY. Depending on the type of measurement (level or volume), MIL-L-23886 specifies that the indicated level or volume shall be within plus or minus three percent of full scale of the actual level or volume of liquid in the tank. Repeatability of the indicators shall be within plus or minus one percent of full scale at any point on the scale. MIL-L-23886 also specifies the accuracy of the control circuit. The dead band of the control circuit shall not exceed plus or minus three percent of full scale, including instrument hysteresis. Repeatability of the control point contact shall be within plus or minus one percent of full scale.

504-9.4.2 DIRECT READING DEVICES

504-9.4.2.1 Sounding Rule. A sounding rule is a length of conjoined sections of naval brass plate that is jointed in order to fold into a compact unit upon removal from the tank. The sounding rule is graduated in feet and inches, beginning at the bottom of the rule. Sounding rules are individually designed for each tank and are not interchangeable. The sounding rule is permanently installed in a sounding tube inside the tank. To perform a level measurement, the sounding rule, attached to the sounding tube cap, is carefully removed from the sounding tube until the portion wetted by the liquid in the tank becomes visible. The liquid level, in feet and inches, is noted. The linear level measurement is then converted into a liquid volume using the appropriate tank capacity curve or table. Sounding rules are often used on fuel, lubricating oil, potable water, and ballast systems.

504-9.4.2.2 Gaging Tape. A gaging tape consists of a frame with an attached handle, a tape with a nonsparking plumb bob, a tape wiper, and a drum. The tape is graduated in feet and inches, beginning at the plumb bob. The tape is wound on the drum by a handcrank. To perform a level measurement, the plumb bob is lowered into the tank through a sounding connection at the tank top until the tape tension changes as a result of the plumb bob contacting the tank bottom. The tape is then rewound until the portion wetted by the liquid in the tank becomes visible. The liquid level, in feet and inches, is noted. The linear level measurement is then converted into a liquid volume using the appropriate tank capacity curve or table. Gaging tapes are often used on fuel, lubricating oil, cargo oil, and ballast systems.

504-9.4.2.3 Top Sounding (Ullage) Tape. Top sounding, or ullage, is an alternate method of sounding tanks, originally developed for use with distillate or diesel marine fuels due to difficulties in distinguishing the wetted and non-wetted portions of the tape. This method is similar to the gaging tape method except that it measures the amount of liquid absent from the tank rather than the amount remaining in the tank. This method requires modification of the plumb bob so that it will produce a plopping sound upon entering into and retracting from the liquid surface. The standard brass bob may be altered as shown in Figure 504–9–1, or a new bob can be manufactured from round brass stock. When the modified bob is attached to the tape end, a two inch length of chain (equal to the length removed from the bob) is added to ensure a correct tape reading. Bottom sounding capacity curves or tables must be reversed to use the top sounding method, i.e., the level measurement obtained from the top sounding method must be subtracted from the total length of the tank, and the resulting figure must be applied to the capacity curve or table to determine the volume of liquid remaining in the tank. Tapes are furnished in lengths of 33, 50, 75, and 100 feet.s.

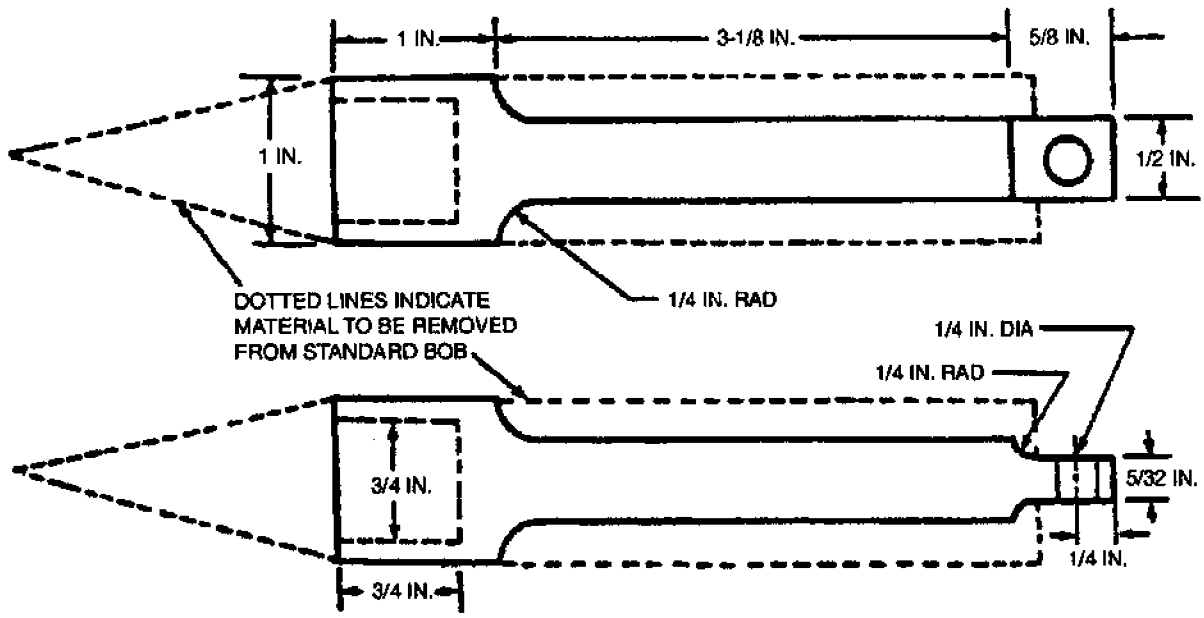



Figure 504-9-1. Optimum Plumb Bob Design

504-9.4.2.4 Float Gage. Float gages utilize a float as the primary level measurement mechanism. The float, by reason of its buoyancy, precisely tracks the varying level of liquid in the tank. A tape with a counterweight is attached to the float. The tape, graduated in feet, inches, and eighths of an inch, is visible through a vaportight window where it passes over a sheave in a gage head atop the tank. This measurement represents the distance from the top of the tank to the surface of the liquid (ullage). A capacity curve or table is used to convert this linear measurement to a tank volume. The float may be raised and lowered manually by a crank on the sheave. In one variation of this system, instead of the tape being graduated, the float action is transmitted mechanically from the sheave to a pointer on the scale. Float gages are often used in cargo oil systems.

504-9.4.3 INDIRECT READING DEVICES

504-9.4.3.1 Static Head (Hydrostatic) Liquid Level Indicator. Static head liquid level indicating systems operate on the principle of balancing a head of liquid in a tank against a column of liquid in a manometer indicator or against the pressure sensing element of a dial gage. The indicator may be calibrated in units of liquid depth, weight, or volume. Three basic types of static head systems are **pneumatic systems, closed systems** , and **water-filled systems** .

504-9.4.3.2 Static Head, Pneumatic Liquid Level System. Pneumatic Liquid Level System. Pneumatic liquid level systems are systems that utilize air pressure to accomplish liquid level measurement. Air is used to transmit the head pressure of the liquid in the tank to a pressure sensing instrument and to purge the system of unwanted liquid. Two types of pneumatic systems are the **standpipe/airbell system** and the **force balance system** .

504-9.4.3.3 Static Head, Pneumatic, Standpipe/Airbell System. The standpipe/airbell system is shown in . The standpipe/airbell system consists of a standpipe with a bell-shaped fixture affixed to its end. This assembly is mounted in the tank with the airbell near the tank bottom. Liquid may enter the airbell, but its volume is sized to prevent the liquid from entering the standpipe when the tank is refilled. The standpipe connects the airbell to the tank top penetration fitting. Piping or tubing connected to the tank top penetration runs to the high pressure connection of the liquid level indicator and the compressed air supply (purge air). Pressure from the air supply pressurizes the piping from the indicator to the airbell, purging the tank liquid from the airbell. Surplus air escapes out the airbell bottom. The amount of pressure at the bottom of the tank varies directly with the height (head) of the tank liquid. This head pressure is transmitted, via a column of air, to a pressure sensing instrument. Since the bottom of the airbell is a short distance above the lowest point of the tank, the indicator scale is graduated to reflect this difference, thus giving a true zero liquid level reading.

504-9.4.3.3.1 If the tank is either a pressurized tank or a closed tank not vented to atmosphere, an equalizer piping line runs from the low pressure connection of the indicator to a connection on the tank top, as shown in Figure 504–9–2. This configuration prevents either a liquid loss in the manometer indicator or rupture of the pressure sensing element, as appropriate, when inadvertent overflow or excess tank pressurization occurs. This configuration also ensures that the indicator will indicate only the level equal to the liquid head in the tank, since both the tank and the indicator are referenced to the same pressure.

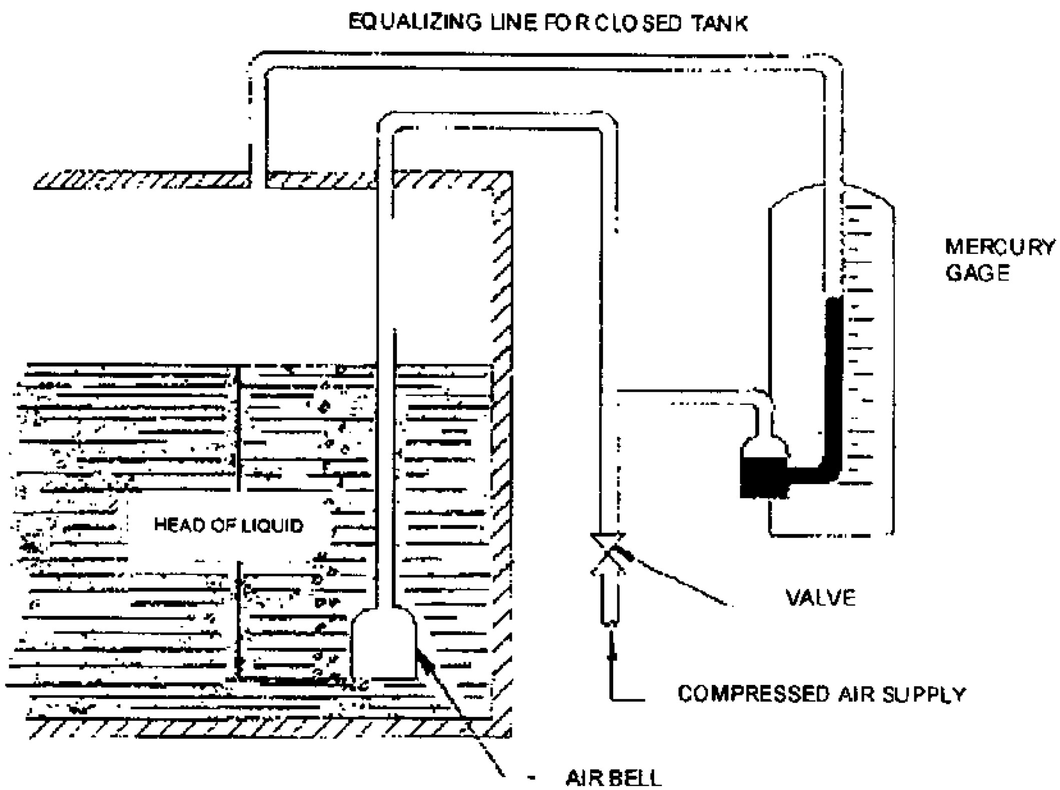



Figure 504-9-2. Simple Hydrostatic Head Liquid level Indicating System

504-9.4.3.3.2 Pneumatic static head liquid level systems are designed for use on vented and pressurized tanks where the stored liquid is at approximately ambient temperature. Purge air can be supplied by either a hand pump or by a compressed air system. Systems provided with a hand pump to supply the purge air are commonly used on small vented tanks where the indicator is locally mounted or located in the same space or compartment as the tank. Systems using compressed air to provide an intermittent or continuous supply of purge air are commonly used on storage or service tanks where the indicator is located at a distance from the tank, and a hand pump would not supply enough air to clear the connection lines and standpipe. Intermittent purge systems are used on those tanks not requiring a continuous indication such as large storage tanks. Continuous purge systems supply constant, low pressure, low volume air to the standpipe/airbell, keeping it clear of tank contents and providing a continuous reading. Continuous purge systems are usually used on those tanks requiring constant monitoring such as fuel oil service tanks.

504-9.4.3.4 Static Head, Pneumatic, Force Balance System. A force balance pneumatic system is commonly used as an internal draft gage. This installation is shown in Figure 504–9–3. An internal draft gage is used to obtain an inside ship's draft reading when direct observation of hull draft marks is impractical. A force balance pneumatic system consists of a pneumatic pressure supply and regulator, diaphragm/transmitter, baffle, and nozzle. The diaphragm/baffle/nozzle assembly is located at the hull bottom. The diaphragm/transmitter is flange mounted to the sea chest, and air supply and output signal lines connect the transmitter to the pressure indicator above. The regulated air pressure supply provides pressure to the instrument side of the diaphragm. The head pressure of the tank liquid is applied to the other side of the diaphragm. The pressure on the diaphragm moves the baffle with respect to the nozzle, thus providing a variable restriction to the outflow of air from the transmitter to the pressure indicator. This action keeps the air pressure on the instrument side of the diaphragm equal to the head pressure. Any increase in head pressure (corresponding to an increase in liquid level) moves the diaphragm and baffle toward the nozzle, restricting the outflow of air and increasing the balancing air pressure inside the transmitter until pressure equilibrium is reached. Similarly, a decrease in head pressure (corresponding to a decrease in liquid level) causes the diaphragm and baffle to move away from the nozzle, allowing more air to escape and decreasing the balancing air pressure until pressure equilibrium is again established. The balancing air pressure is used as the output signal to the indicator, which is usually marked in units of feet of seawater.

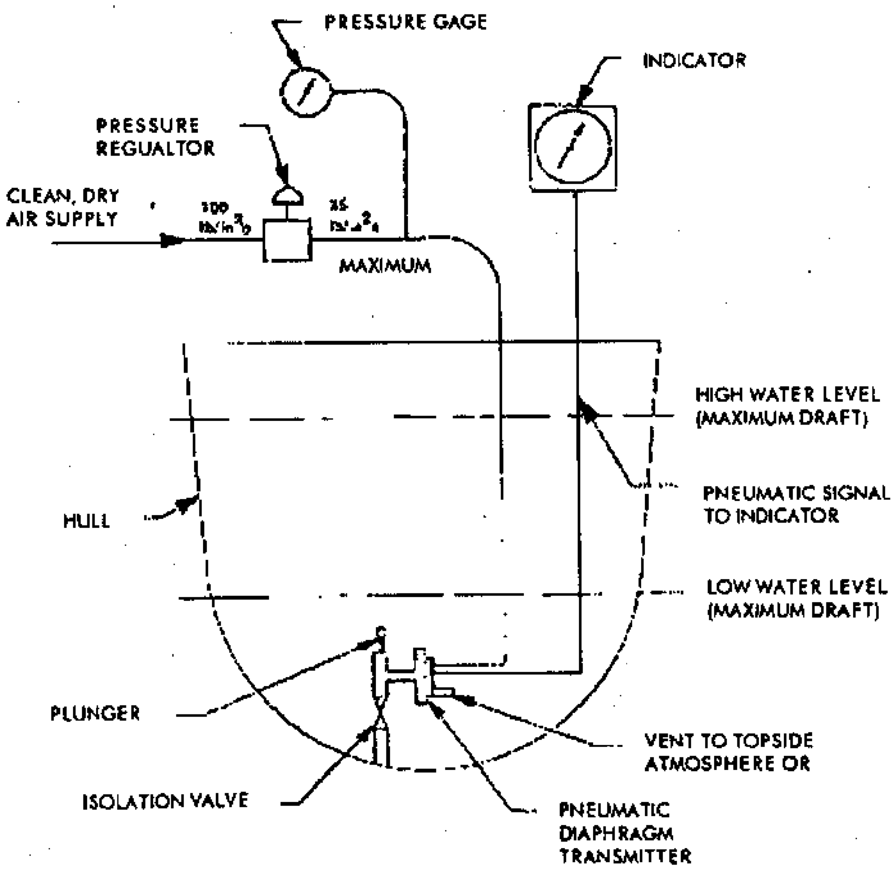



Figure 504-9-3. Internal Draft Gage System

504-9.4.3.5 Static Head, Closed System. The sensing portion of a closed system consists of a liquid-filled differential pressure measuring unit connected by capillary tubing with diaphragm or bellows-type sealed sensing heads at each pressure source. The differential pressure unit is used to actuate a direct reading dial gage and/or electrical transmitters. Closed systems are used primarily as alternatives to pneumatic and water-filled systems where these systems are not suitable. Use of closed systems is limited to applications where the available differential pressure is adequate for proper functioning of sensing elements. Closed systems are classified as either direct-actuated or electrical.

504-9.4.3.6 Static Head, Closed System, Direct-Actuated. A differential pressure sealed sensor system is an example of a direct-actuated closed system. The differential pressure systems that are used for tank level measurement are manufactured by ITT Barton. The system consists of a dial gage, differential pressure unit (DPU), capillary tubing, and two external bellows sensing elements. The entire system is filled with a non-corrosive fill fluid. The fill fluid contained in the sealed sensor system hydraulically transfers the pressure from the sensing elements to the DPU. The DPU actuates a direct reading dial gage. Each sensing element contains a sealed bellows or diaphragm which serves as the separating member between the process media and the fill fluid. Tank level measurement is accomplished by installing a low pressure external bellows sensing element at the bottom of the tank and a high pressure external bellows sensing element at the top of the tank. These elements are connected to the low and high pressure chambers, respectively, of the DPU. The difference between the low and high pressure indications is inversely proportional to the level of liquid in the tank; i.e., as the liquid level decreases, the pressure differential increases. (This system is known as a reverse-acting system.) DP sensor systems that are used for tank level applications are often outfitted with a low level switch that activates a low level alarm. This system is used for applications where the maximum distance from the sensing head to the indicator is fifty feet and where the indicator is located in the same compartment as the tank. See Section 4 for a more extensive discussion of differential pressure gage systems.

504-9.4.3.7 Static Head, Closed System, Electrical. An electrical closed system operates in the same manner and is composed of the same elements as the direct-actuated closed system except that the DPU actuates an electrical or electronic transmitter. With an electrical system, the transmitter receives a direct and continuous signal in the same manner as the direct-actuated system, but it must be electrically energized to transmit a level indication to the receiver gage. This system is used for applications where venting of air from a transmitter may affect ambient pressure, changes in ambient conditions would affect the indicator calibration, an electrical signal is required, the indicator is external to the tank compartment, the distance to the sensing head is greater than fifty feet, or repeater stations are necessary.

504-9.4.3.8 Sattiac Head, Water-Filled System. A water-filled system measures and indicates the difference in pressure between a static and variable head of water. The static head maintains pressure on the high pressure side of the pressure sensing element, and the variable head (which is proportional to water level) maintains pressure on the low pressure side. Water-filled systems are used for level measurement of high temperature water tanks. Basically, the system consists of a remote liquid level indicator, a constant head chamber, a sensing element, connecting piping, and, as an option, a differential pressure transmitter and readout device. When the indicator is installed on a pressurized vessel, a reference head must be provided for comparison with the varying head within the tank. The reference head is provided by the constant head chamber. The chamber is located above the highest level to be measured and has a fill connection and an overflow so that the water level remains fixed. On a tank vented to atmosphere, a constant head chamber is not necessary if the instrument can be located at a specific short distance below the tank bottom. For proper operation, the system must be completely filled with pure water; there shall be no air or leaks in the system. A diagram of this system is shown in Figure 504–9–4. Water-filled systems are manufactured by Yarway Corporation and White Consolidated, Gage and Valve Division.

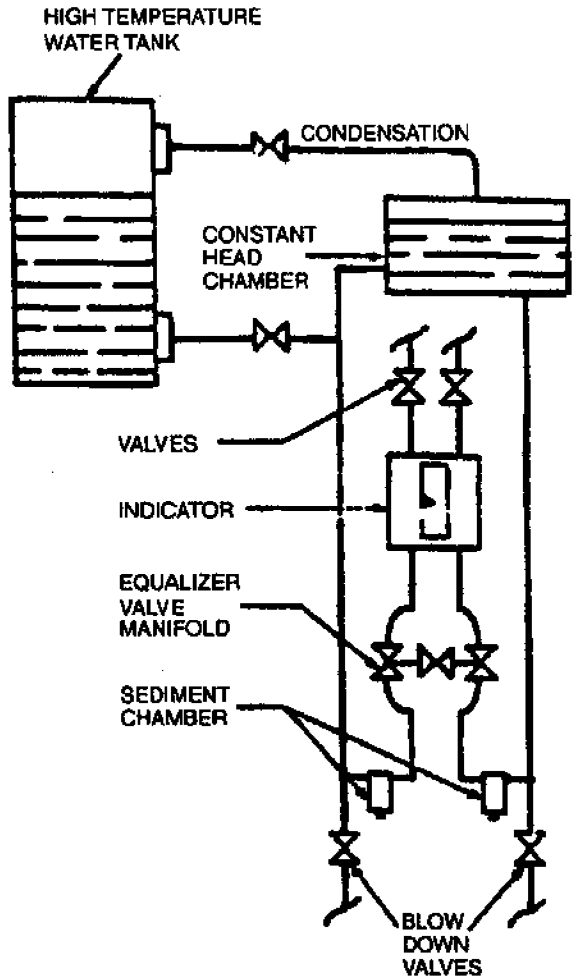



Figure 504-9-4. Water-Filled Static Head System for High-Temperature Water Tanks

504-9.4.3.9 Electrical Liquid Level Indicator. The prevalent types of electrical tank liquid level indicating systems used by the Navy are the **admittance/impedance, magnetic float, time domain reflectometry, capacitance** , and **resistance tape** types. Generally, systems consist of one or more level sensors or transmitters in the tank, a measuring circuit, one or more indicators, and a power supply. Liquids that can be measured include freshwater, seawater, diesel oil, JP fuel oil, lubricating oil, and waste oil. Liquid level is usually measured at the air-water, air-oil, or oil-water interface.

504-9.4.3.10 Electrical, Admittance/Impedance Liquid Level Indicator. The admittance/impedance liquid level indicator consists of a probe and transmitter. The probe is a Teflon-covered 1/2 inch diameter steel rod. The transmitter impresses a low power radio frequency voltage between the probe and ground. The admittance of the probe, which changes as the liquid level changes, is measured electrically by a bridge circuit and presented to the indicator as a volume for visual display.

504-9.4.3.11 Electrical, Magnetic Float Liquid Level Indicators. Typical magnetic float level indicators are shown in Figure 504–9–5. The magnetic float level indicators are manufactured by Gems Sensors. Each tank level indicator (TLI) system comprises different equipment and accessories to meet requirements of an individual installation. TLI system components can be divided into the following four general categories: **fluid level detection devices, receiver devices, remote fluid level indicating** and **alarm devices** , and**installation accessories** .

These components are discussed below. As the fluid level in the tank changes, the magnetic float moves up or down the transmitter. As shown in , bar magnets in the float operate tap switches in a two-at-a-time, three-at-a-time, two-at-a-time closing sequence as the float moves up the transmitter. When two adjacent tap switches are closed, the effective electrical tap point on the voltage divider network is halfway between two switches. As the float closes the next tap switch (the first two are still closed), the effective tap point is halfway between the first and third tap switches; that is, at the middle switch. This middle point is one-half inch from the effective tap point established when only two tap switches were closed. As a result, voltage drops correspond to one-half inch increments of float travel.

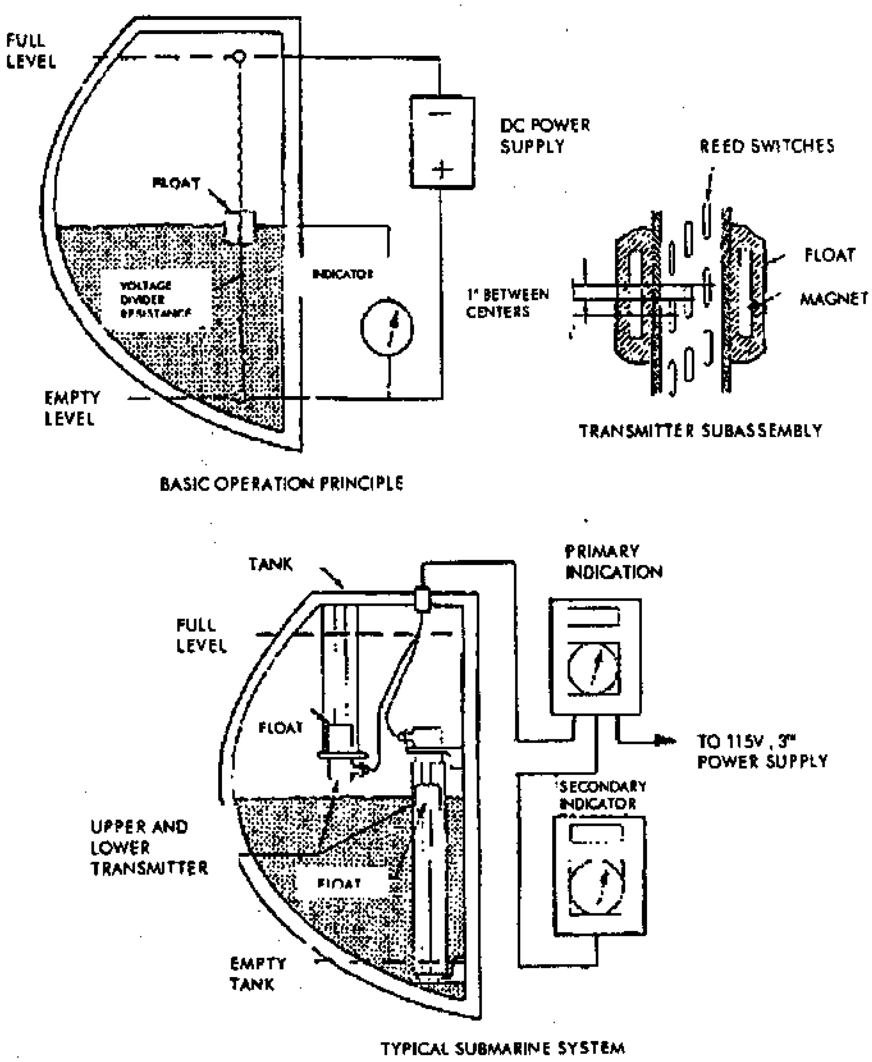



Figure 504-9-5. Electromagnetic Float Type Level Indicator

504-9.4.3.11.1 When two or more transmitters are installed in a tank, all except the bottom transmitter are equipped with a transfer switch of the type shown on the upper transmitter of Figure 504–9–5. The transfer switch is a magnetically operated reed switch connected between the common conductor (to the tap switch resistances) in one transmitter and the common conductor in the next lower transmitter. The transfer switch is held closed when the float on its transmitter is at its bottom limit. As the float rises with the fluid level, the transfer switch opens and disconnects the tap switches in the lower transmitter. The transfer switch action is required to open the common conductor circuit to lower transmitter tap switches. The uppermost of lower transmitter tap switches is held closed at this time, since the lower transmitter float is at its top limit of travel. The resulting voltage change produced by the changing tank level is processed by the receiver module and the liquid level is indicated on the meter.

504-9.4.3.12 Fluid Level Detection Devices. Fluid level detection devices, or transmitters, are installed in tanks to convert the fluid level to an electrical signal. The transmitter consists of a network of voltage divider resistors and magnetic reed switches. These are contained in silicon rubber, potted in a mylar tube that is surrounded by a neoprene tube, and mounted in a stainless steel tube. Electrical leads connecting to the resistors and magnetic reed switches are brought to electrical connectors which can be located at the top, bottom, or both ends of the transmitter.

504-9.4.3.13 Receiver Devices. Receiver devices are used to supply electric power and to convert the electrical signals generated by level detection devices to deflections of a pointer on a meter. Two types of receiver devices are available with the TLI system. Some primary receiver modules perform level indication, alarm generation, and alarm indication functions for one tank. A receiver panel can provide these functions for four to fifteen tanks.

504-9.4.3.14 Remote Level Indicating and Alarm Devices. Remote level indicating and alarm devices are used to indicate the tank fluid or a high or low level alarm condition in a remote or secondary location. Remote level indicators may be located in Damage Control Central, Fueling Central, or the Engineering Log Room. Remote level indicators may be used for a single tank or multiple tanks in a single receiver module.

504-9.4.3.15 Installation Accessories. Installation accessories consist of various types of installation mounting brackets and the stuffing tube penetration assembly. Mounting brackets are available for bulkhead welding, mounting to sounding tubes, tank ladders, or standpipes.

504-9.4.3.16 Electrical, Time Domain Reflectometry (TDR) Liquid Level Indicator. The TDR liquid level indicators, manufactured by Triumph Controls, Incorporated, operate according to the distributed circuit theory that states if a pulse is launched onto a transmission line with segments of differing characteristic impedances, pulse reflections occur at each impedance mismatch. The TDR liquid level indicator consists of a sensor, electronics unit, and display unit. The sensor is a dual-conductor cable installed in a standpipe with a series of open ports along its length. The sensor, electrically resembling a coaxial transmission line, allows the tank’s contents to flow freely between the conductors and act as the line dielectric. The velocity of the pulse along the transmission line is dependent upon the dielectric property of the material separating the line’s conductors. An electromagnetic pulse transmitted over the inner conductor returns a reflection at the fluid interface, as a result of the differing impedances at this interface. The pulse transit time and reflection amplitudes are used to determine the location of the interface, i.e., the level of the tank liquid.

504-9.4.3.16.1 The electronics unit contains a power supply, a TDR excitation source that launches a high frequency electromagnetic pulse to the sensor and samples the return signals, and a signal processor that analyzes the return signals and digitally transfers this information to the display unit. The display unit accepts the digital data from the signal processor and converts the fluid level measurement to a fluid volume using capacity tables entered into memory. The volume indication is displayed on the analog readout.

504-9.4.3.17 Electrical, Capacitance Liquid Level Indicator. A capacitance liquid level indicator consists of a capacitance probe located inside the tank, an oscillator unit whose output signal varies with probe capacitance, and an amplifier and indicator unit which translates the oscillator signal to a pointer deflection on a meter. The tank probe may be flexible or rigid and is insulated from the contents of the tank by a dielectric material such as Teflon, nylon, or polyvinyl chloride. The flexible probe is fastened a short distance from the inside wall of the tank in a position as near vertical as possible. In operation, the capacitance probe reading will be the lowest with air between the tank wall and the probe. When liquid is added to the tank, it surrounds the probe and the electrostatic field between the insulated probe and the tank wall changes. This capacitance change is detected by a bridge circuit and presented to the indicator as a volume for visual display.

504-9.4.3.18 Electrical, Resistance Tape Liqud Level Indicator. The resistance tape liquid level indicator, manufactured by Metritape, Incorporated, consists of an in-tank sensor, sensor housing, breather assembly, and power supply/level indicator. The in-tank sensor uses a precisely formed helical resistor to locate the air/liquid boundary for purposes of liquid level gaging. The sensor backbone is a high-strength stainless steel strip having a gold contact stripe down the center of the front side, and film insulation wrapped around both the edges and the back. A nichrome resistance helix is wound precisely around this partially insulated core at 1/4 inch intervals, and the helix is gold-finished so that gold-on-gold contact can occur between helix turns and the gold stripe on the base strip. A sealed and compliant envelope, usually of Teflon fluorocarbon film, encloses the electrical core assembly. A light pressure exerted on the outer jacket collapses the jacket and forces the helix turns to short against the gold stripe. When the surrounding jacket is not so collapsed, the helix turns stand away from the base strip and are insulated therefrom by the film insulation. The sensor, available in continuous lengths from three feet to over one hundred feet, is suspended vertically from the top of the tank. As liquid is introduced into the tank, hydrostatic pressure collapses the sealed outer envelope and shorts the wound helix progressively against the base strip, from the helix bottom end (which is welded to the base strip) to a location close to the liquid surface. The wound helix above the liquid surface remains unshorted and its resistance, and thus its length, is precisely measurable across two leadwires extending out the top of the sensor, with the sensor base strip serving as the return path from the point of uppermost helix contact. This sensor essentially forms an active electro-ohmic resistor which extends from the top of the tank to the liquid surface and is directly analogous to a top sounding tape. As liquid level falls, helix contacts are relieved of pressure and open, causing a proportionate increase in the measured sensor resistance. As liquid level rises, helix turns are progressively shorted, bringing sensor resistance to near zero at the full tank condition. Because the sensor resides directly in the medium being measured, it provides an excellent site for mounting one or more resistance temperature detectors (RTDs). The resultant sensor is a level/temperature sensor.

504-9.4.3.18.1 The resistance tape liquid level indicator, manufactured by Metritape, Incorporated, consists of an in-tank sensor, sensor housing, breather assembly, and power supply/level indicator. The in-tank sensor, shown in ??? uses a precisely formed helical resistor to locate the air/liquid boundary for purposes of liquid level gaging. The sensor backbone is a high-strength stainless steel strip having a gold contact stripe down the center of the front side, and film insulation wrapped around both the edges and the back. A nichrome resistance helix is wound precisely around this partially insulated core at 1/4 inch intervals, and the helix is gold-finished so that gold-on-gold contact can occur between helix turns and the gold stripe on the base strip. A sealed and compliant envelope, usually of Teflon fluorocarbon film, encloses the electrical core assembly. A light pressure exerted on the outer jacket collapses the jacket and forces the helix turns to short against the gold stripe. When the surrounding jacket is not so collapsed, the helix turns stand away from the base strip and are insulated therefrom by the film insulation. The sensor, available in continuous lengths from three feet to over one hundred feet, is suspended vertically from the top of the tank. As liquid is introduced into the tank, hydrostatic pressure collapses the sealed outer envelope and shorts the wound helix progressively against the base strip, from the helix bottom end (which is welded to the base strip) to a location close to the liquid surface. The wound helix above the liquid surface remains unshorted and its resistance, and thus its length, is precisely measurable across two leadwires extending out the top of the sensor, with the sensor base strip serving as the return path from the point of uppermost helix contact. This sensor essentially forms an active electro-ohmic resistor which extends from the top of the tank to the liquid surface and is directly analogous to a top sounding tape. As liquid level falls, helix contacts are relieved of pressure and open, causing a proportionate increase in the measured sensor resistance. As liquid level rises, helix turns are progressively shorted, bringing sensor resistance to near zero at the full tank condition. Because the sensor resides directly in the medium being measured, it provides an excellent site for mounting one or more resistance temperature detectors (RTDs). The resultant sensor is a level/temperature sensor.

## 504-9.5 CARE AND MAINTENANCE

504-9.5.1 DIRECT READING DEVICES. Sounding rules and float gages require virtually no maintenance. Gaging tapes should be wiped down and dried after each use.

504-9.5.2 PNEUMATIC SYSTEMS. Proper operation of any pneumatic system is largely dependent upon a clean air supply. Therefore, system filters should be drained daily and changed at regular intervals. Recommended preventive maintenance procedures to be performed on a scheduled basis are provided in the Planned Maintenance System (PMS) documentation. These maintenance procedures are outlined in the appropriate Maintenance Requirement Cards (MRCs) and technical manuals for each specific system and application.

504-9.5.3 CLOSED SYSTEMS. Under ordinary conditions of operation, these systems require virtually no maintenance. If sensors are accessible, diaphragms or bellows may be checked occasionally for any accumulation of dirt, tars, or other foreign substances. If accumulations are present, they may be removed with a soft brush and suitable solvent.

**CAUTION**

**DO NOT use a wire brush, knife, or other instrument which might perforate the pressure-sensing element.**

504-9.5.4 WATER-FILLED SYSTEMS. When water-filled systems have been properly filled and vented, no further action is required to keep the system operating indefinitely except for an occasional blowdown to remove rust and scale from the piping. After venting the constant head side, time must be allowed for the head chamber to fill with condensate (usually about one half hour) before readings are taken.

**CAUTION**

**Never allow steam to enter the indicator as it will damage the diaphragm.**

504-9.5.4.1 If it becomes necessary to drain the tank, shut all isolation valves so as to lock water in the indicating system to prevent having to vent the piping again when returning to operation. If the indicator must be removed, isolation valves on the piping should be closed for the same reason. To remove the indicator:

1. Secure all electrical power to the unit.
2. Shut all three manifold valves.
3. Open vent valves to release pressure.
4. Disconnect electrical leads.

5. Disconnect tubing at connectors.

504-9.5.4.2 Recommended preventive maintenance procedures to be performed on a scheduled basis are provided in the Planned Maintenance System (PMS) documentation. These maintenance procedures are outlined in the appropriate Maintenance Requirement Cards (MRCs) and technical manuals for each specific system and application.

504-9.5.5 ELECTRICAL LIQUID LEVEL INDICATORS. Under ordinary conditions of operation, these systems require virtually no maintenance. However, if the sensors are accessible, they should be checked occasionally for any accumulation of dirt, sludge and other foreign substances. If accumulations are present, they can be removed with a soft brush or rag and a suitable solvent. Recommended preventive maintenance procedures to be performed on a regularly scheduled basis are provided in the Planned Maintenance System (PMS) documentation. These maintenance procedures are outlined in the appropriate Maintenance Requirement Cards (MRCs) and technical manuals for each specific system and application. On Metritape Corporation units, the desiccant filter must be changed on a regular basis to ensure moisture does not enter the sensor internals.

## 504-9.6 CALIBRATION

504-9.6.1 DIRECT READING DEVICES. Direct reading devices require no calibration.

504-9.6.2 PNEUMATIC SYSTEMS. Since proper operation of all TLIs depends upon maintaining a true balance between the liquid head and the indicating medium in the gage, correct readings will be obtained only when the scale is properly installed. The first step in adjusting the scale to the gage is to measure accurately the distance between the lowest point of the tank and the zero line of the measuring chamber or airbell (the point at which it is open to the tank). When this distance has been determined, the amount of liquid remaining in the tank when the level has reached the measuring chamber zero line can be computed (using the geometry of the tank and conversion factors listed in Table 504-9-1). The scale must then be adjusted so that when the level of the fluid in the tank drops to the zero line, it will register the actual amount of liquid in the tank. If this procedure is not performed and the scale is left to read zero when the liquid level reaches the zero line, all the level readings will be in error by an amount corresponding to the amount of liquid actually in the tank when the level reaches the zero line.

504-9.6.3 CLOSED SYSTEMS. All system securing and tag-out procedures shall be performed prior to calibration of the system. The specific procedures for calibrating the Barton DP gage are outlined in the applicable technical manual. However, the general method of calibration for all DP gages, regardless of the application, is the same. The remote low pressure sensor housing is vented to atmosphere. The high pressure sensor housing is placed in a special test housing and is connected to a calibrated portable pressure source. The calibrator is used to apply pressure to the sensor to simulate filling and emptying the tank. Using the calibrated pressure source, the gage is cycled twice through its full pressure range by increasing and decreasing the applied pressure, to remove any hysteresis. Reference measurements are made at five equally spaced intervals over the entire range (both upscale and downscale). Precaution is taken to avoid pressure overshoot. Should overshoot occur, the pressure is restored to the previous reference point and the procedure is continued. Readings are taken at each reference point before and after the center of the gage dial is tapped in order to determine any friction error. Depending on the results of the above reference measurement, appropriate adjustment or repair to the gage is performed. A final reference measurement, in accordance with the above procedure, is conducted to ensure that the gage satisfies the specified accuracy requirements. Differential pressure gages are covered by NAVSEA's Metrology and Calibration Program. Their calibration cycle is six months. Refer to the Metrology Requirements List, NAVSEA OD45845, Section 1 for a list of official calibration procedures covering these instruments.

504-9.6.4 WATER—FILLED SYSTEMS. The indicator shall be removed from the system when troubleshooting or recalibration is necessary. A manometer or digital pressure indicator, graduated in inches of water, and a means for applying a variable differential pressure are required. Eliminate all air from the system if water is to be used to obtain a differential pressure. To check the calibration, establish static differential pressure across the indicator with the pointer positioned successively at each major scale division. Take corresponding manometer readings in inches of water up and down the scale and average them. Note that the differential pressure does not directly correspond to the indicator reading since an initial differential pressure is needed to move the pointer to the high mark. There is also a correction needed for pressure and temperature variables. Hence when correct cold water suppression (initial differential pressure) is applied, the pointer should be at the high graduation mark. If it is not, make a correction with the adjustment screw inside the indicator side cover plate.

**CAUTION**

**DO NOT turn this screw more than 1/8 turn from the initial position. If the pointer hand is considerably off the high mark, reposition it on the shaft and then perform the above procedure. A range adjustment screw is also located inside the indicator cover plate. One turn of the screw is about 1/8 inch of water per unit of pointer movement. After the range adjustment, perform the high mark adjustment again. Consult technical manuals supplied with the system for detailed disassembly, maintenance, and calibration information.**

504-9.6.5 ELECTRICAL LIQUID LEVEL INDICATORS. Each liquid level indicator system is calibrated to operate in a specific tank. Before it can be calibrated, the power supply must be checked to ensure it is operating at the specified output voltage, the signal conditioner must be checked to ensure it is providing the proper output signal range, the indicator meter must be checked to ensure it is operating linearly and it is zeroed and full ranged for the output from the signal conditioner and that all cable and wire connections are tight. After all of the preliminary checks are completed, a copy of the tank capacity curve for the tank must be obtained. Based upon the total tank capacity, an increment of 1, 2 or 5 times 10n is selected to obtain a minimum of twenty reference points along the capacity curve within the measurable range of the tank sensor. Using these selected reference points, a simulated signal is generated from the sensor to simulate filling the tank with the measured fluid and the output on the meter dial is marked to correspond to the appropriate liquid level. This is repeated for all selected points until the meter dial is completely marked with the correct indications. On the new digital type meters, this information is entered into an EPROM on the circuit board which takes the signal from the sensor and signal conditioner and converts it to a digital signal for display on the digital indicator.

# SECTION 10.

# THERMOMETERS

## 504-10.1 ENGINEERING PRINCIPLES

504-10.1.1 Temperature is the quantitative measure of the relative hotness or coldness of an object as indicated on or referred to a standard scale. A person considers things to be hot or cold relative to ones own body temperature which is 98.6°F, on average. The ability to sense temperature is a result of a physical law, which states that heat, as a form of energy, will always flow from a hotter body to a colder body, regardless of the masses of the two bodies. If one touches an object at a higher temperature than their body temperature, heat will flow from the object to their body causing the sensation of hotness.

504-10.1.2 The two most important effects produced by heat are the change of temperature of an object and the change of state of a substance. When heat is added to water that is originally at room temperature, the first effect will be an increase in the temperature of the water. The water temperature will continue to increase as heat is added until the water boils. The temperature that water changes state of matter from a liquid to a gas is known as the boiling point. Likewise, if heat is removed from water it will change state from a liquid to a solid at a temperature known as the freezing point.

504-10.1.3 The temperatures at which common substances change state provide repeatable reference points as a scale of measure to quantitatively define how cold or hot an object is. The instrument used to measure temperature is the thermometer. The temperature scales most commonly used are the Fahrenheit scale and the Celsius scale. The important fixed points to remember as a baseline on both of these scales are the boiling and freezing points of distilled water. On the Fahrenheit scale, the freezing point of water is set at 32°F and the boiling point is 212°F. On the Celsius scale, the freezing point is set at 0°C and the boiling point is 100°C.

504-10.1.4 The following formulas can be used to convert temperature measurements from one scale to another:

$$°C = (°F - 32°)\ 5/9 \quad \text{and} \quad °F = 9/5\ (°C) + 32°$$

504-10.1.5 In some cases it may be necessary to convert an equivalent interval or step change in temperature from one scale to another. Referencing the freezing and boiling points for water on both scales, it can be determined that a temperature interval of 100°C is equivalent to an interval of 180°F. In other words, a 1°C interval is equivalent to a 1.8°F interval, or a 1°F interval is equivalent to a 0.555°C interval.

## 504-10.2 DEFINITIONS

504-10.2.1 LIQUID-IN-GLASS THERMOMETER. A temperature measuring instrument whose indications are based on the volumetric expansion of a liquid in a glass column relative to temperature.

504-10.2.2 BIMETALLIC THERMOMETER. A temperature measuring instrument whose indications are based on the force generated when two fused metal strips, composed of different materials, thermally expand or contract at different rates.

504-10.2.3 FILLED—SYSTEM THERMOMETER. A temperature measuring instrument whose indications are based on the actuation of a Bourdon tube pressure element due to one of the following physical phenomena: thermal expansion/contraction of a liquid, pressure change of a gas relative to temperature, vapor pressure change of a volatile liquid relative to temperature.

504-10.2.4 RESISTANCE THERMOMETER. A temperature measuring instrument whose indications are based on the influence of temperature on the electrical resistance of a metal wire sensing element.

504-10.2.5 PYROMETER. A temperature measuring instrument whose indications are based on the direct current or voltage generated in an electrical circuit consisting of two dissimilar metal wires, joined at both ends, when a temperature differential exists between the two junctions.

504-10.2.6 RESISTANCE TEMPERATURE DETECTOR (RTD). A temperature sensor consisting of a metal wire element whose electrical resistance will change linearly relative to temperature.

504-10.2.7 THERMOCOUPLE. A temperature sensor consisting of two dissimilar metal wires joined at one end to form the measurement junction of a pyrometer circuit.

504-10.2.8 THERMOWELL. A closed-end tube designed to accommodate a temperature sensor in piping installations.

## 504-10.3 SAFETY

504-10.3.1 THERMOWELLS. Thermowell material selection and installation methods for all shipboard thermometers must strictly adhere to the practices stated in NAVSHIPS Drawing 810-1385917.

504-10.3.2 DIRECT IMMERSION INSTALLATIONS. Thermometers directly immersed in the medium being measured should never be removed for replacement or servicing while the ship system is operating or under pressure.

504-10.3.3 HEATED PARTS. Avoid skin contact with heated stems, sheaths, bulbs or temperature calibrator chucks to reduce risk of serious burns. Never place heated parts in the surrounding work area where they may be accidentally handled, cause damage or topple onto the operator or floor.

## 504-10.4 DESCRIPTION

504-10.4.1 LIQUID-IN-GLASS THERMOMETERS. Liquid-in-glass thermometers consist of a sealed glass fixture partially filled with liquid whose volume changes relative to temperature. The glass fixture consists of a bulb or reservoir at its base with a narrow capillary tube extending from the bulb. The operation of a liquid-in-glass thermometer is dependent on the temperature coefficient of expansion of the liquid being greater than the glass bulb in which it fills. An increase in the temperature of the thermometer’s bulb or reservoir causes the liquid to expand and rise in the narrow capillary of the glass column. The use of a narrow capillary tube acts to amplify the rise of the liquid column resulting in improved accuracy and resolution. Also, the tube glass acts as a magnifying lens to further increase measurement resolution. Liquid-in-glass thermometers for laboratory and medical applications typically have temperature scale graduations etched directly on the glass capillary column. These thermometers are constructed in accordance with the Standard Specification for American Society for Testing and Materials (ASTM) Thermometers E-1. A comprehensive listing of ASTM thermometers by temperature range and scale graduations is provided in the E-1 standard.

504-10.4.2 BIMETALLIC THERMOMETERS. Bimetallic thermometers built and tested to MIL-I-17244 consist of two dissimilar metal strips fused together in a spiral or helix configuration. The spiral sensing element is enclosed in a protective metal tube with one end of the element affixed to the closed-end of the tube and a pointer stem and pointer attached to the other end of the element. The helical element and likewise the indicating pointer will rotate as the dissimilar metal strips thermally expand or contract at different rates. The pointer and temperature scale dial are housed in a circular metal case, which is affixed atop the sensing stem. A 3/4″-28-UN-2A union fitting is permanently attached to the protective tube for standard thermowell installations. MIL-I-17244 thermometers have standard dial size diameters of 3 and 5 inches. The sensing stem can be connected to the bottom or back of the dial case. The stem size is available for insertion lengths of 2, 4 or 6 inches. MIL-I-17244 bimetallic thermometers that are designed for use in weapons and ammunition magazines have pointer indexes that are pushed by the pointer to display the minimum and maximum temperatures inside the compartment. A reset knob in the center of the dial allows the user to realign the indexes with the temperature indication pointer when pressed. See Figure 504–10–1 for basic bimetallic thermometer construction.

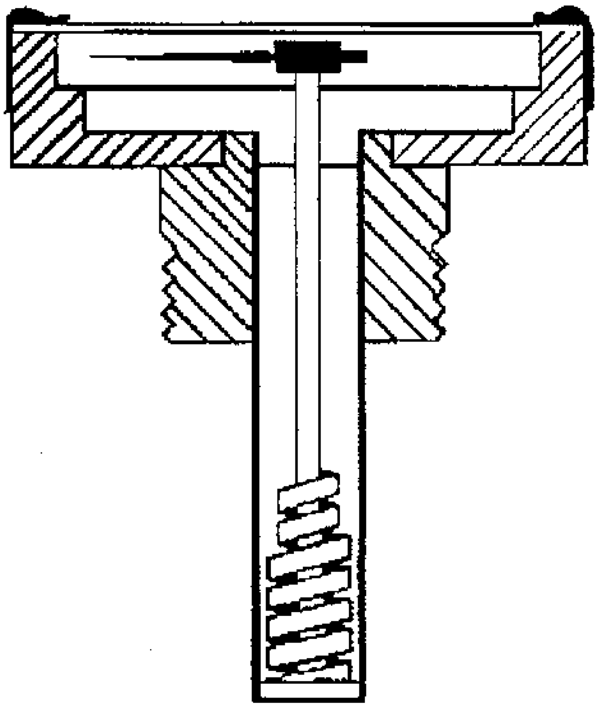


Figure 504-10-1. Bimetallic Thermometer

504-10.4.3 FILLED—SYSTEM THERMOMETERS. Filled-system or gas actuated thermometers built and tested to MIL-T-19646 are hermetically-sealed systems consisting of a sensing bulb, a capillary extension, a Bourdon tube assembly and a liquid, gas, or combination liquid/gas fill. A change in the sensing bulb temperature will result in a pressure change of the thermometer's internal fill fluid or gas; the pressure change is transmitted through the capillary extension to the Bourdon tube. A Bourdon tube is a closed and flattened tube formed into a spiral, helix, or arc. The tube will deflect when its internal pressure changes. The Bourdon tube motion is amplified by a mechanical linkage or gear system which in turn drives a indication pointer. The Bourdon tube is housed in a metal case which contains a temperature scale plate and a protective glass window. The Bourdon tube movement is compensated for ambient temperature by a bimetallic link, which modifies its motion as required. Thermometers with a combination liquid/gas fill do not have temperature compensation components in the dial case because the system pressure is dominated by the vapor pressure at the liquid/gas boundary in the sensing bulb. MIL-T-19646 filled-system thermometers are available in several system configurations. The thermometer dial size may be 3.5, 4.5, or 8.5 inches in diameter. The capillary extension may be connected to the bottom, back or 5 o'clock position of the dial case. The capillary extension is protected in spiral wound armor and is available in lengths up to 125 feet long. The sensing bulb is available in three different configurations. The class A sensor configuration is constructed for insertion into a bracket which conforms to NAVSEA Drawing 810-1385917. The class A sensor configuration has a 0.375 inch diameter by 3 inch long bulb with a 3/4″-28-UN-2A sliding union fitting. The class B sensor configuration is constructed for direct immersion into the process fluid. The class B sensor configuration has a 0.75 inch diameter by 4.5, 8 or 10 inch long bulb with an integral flange sized for either 600 or 1500 pound steam service applications. The class C sensor configuration is constructed for insertion into a thermowell which meets the requirements of MIL-T-24270. The class C sensor configuration may be either a 0.375 inch diameter by 3 inch long bulb with a 3/4″-28-UN-2A sliding union fitting or a 0. 935 inch diameter by 3 inch long bulb with a 1.25″-18 NEF-2 sliding union fitting. Filled-system thermometers are provided with a red-colored pointer which is set by the user at the maximum normal operating temperature for the ship system being monitored. See Figure 504–10–2 for basic filled-system thermometer construction.

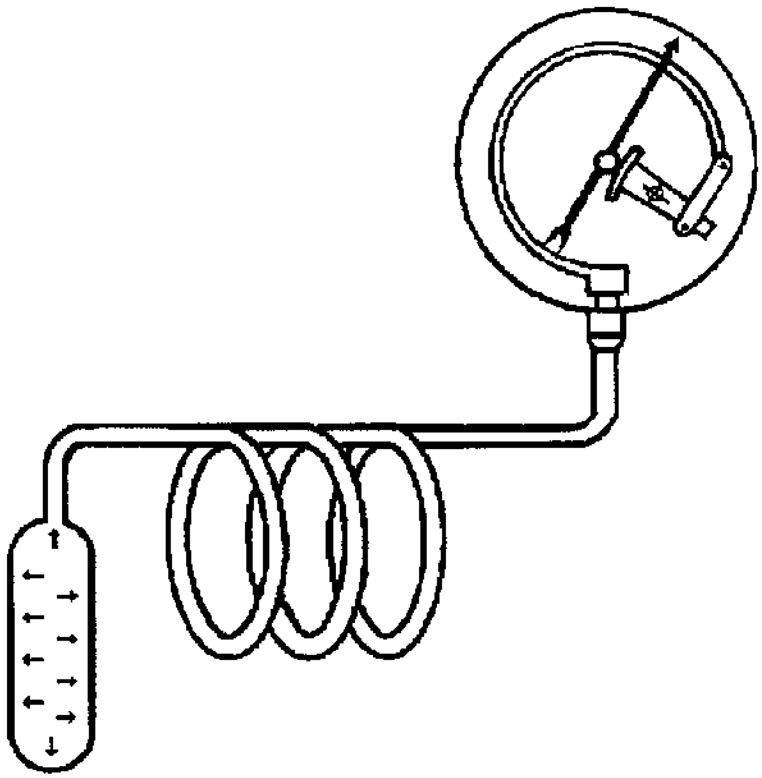


Figure 504-10-2. Filled System Thermometer

504-10.4.4 RESISTANCE THERMOMETERS. A resistance thermometer is a temperature measuring system consisting of a sensor, a resistance-measuring electronic circuit, and a multi-conductor, electrical cable to connect the two components.

504-10.4.5 RTDs. The sensor, commonly referred to as an RTD, is typically a platinum or nickel wire packaged in one of three possible configurations in accordance with MIL-T-24388. RTDs are available as either two or three-wire sensing elements to support different types of the resistance measuring electronic circuits existing in the Fleet. A two-wire RTD has a lead at either end of the sensing element. One lead is color-coded red and the other is white. A three-wire RTD has two leads connected to one end of the sensing element and one lead on the other end. The isolated lead is color-coded red while the two common leads are both color coded white. MIL-T-24388 addresses RTD configurations for thermowell, bare-bulb and embedded mounting installations.

504-10.4.5.1 Thermowell Installations. The MIL-T-24388 RTD configuration for thermowell installations requires the wire sensing element to be housed in a closed-end metal tube or sheath which has an outer diameter of 0.25 inch. A layer of aluminum oxide sand insulates the sensing element from the sheath and provides protection from mechanical stress. The external tip of the RTD sheath is designed to compress against the internal surface of a thermowell as a result of a spring and washer assembly which is affixed to the top end of the sheath, where it mounts to the connection head. A threaded pipe extension resides over the portion of the sheath between the thermowell and connection head to perform the function of rigidly mating the two components. The connection head has a removable cap and a stuffing tube port to allow access to a terminal block which has terminals for electrically connecting the interconnection cable leads to the RTD leads. The threaded pipe extension is available in lengths varying from 1.75 to 7 inches to ensure that the RTD connection head is accessible when different sizes of pipe lagging thickness are required. The standard sheath insertion lengths for thermowell installations are 2.71 and 4.71 inches. See Figure 504–10–3 for RTD thermowell configuration construction.

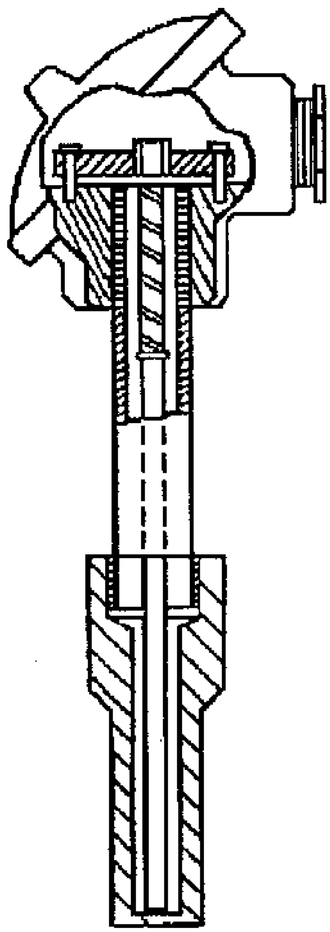


Figure 504-10-3. Thermowell Configuration

504-10.4.5.2 Bare-Bulb Installations. The MIL-T-24388 RTD configuration for bare-bulb or direct immersion installations requires the wire sensing element to be housed in a one-piece construction consisting of a closed-end metal sheath with an integral process connection thread, a copper O-ring, and a electrical connector receptacle. The sheath has an outer diameter of 0.375 inches and has standard insertion lengths of 1.375 and 5.625 inches. The process connection thread size is 3/4″-16 UNF-3A. The connector receptacle at the back-end of the sheath allows for mating the interconnection cable to the RTD. The connector for nickel element RTDs is MIL-C-5015 part number MS3102R-12S-3P, which is a two-pin receptacle that mates with plug part number MS3106F-12S-3S. The connector required for platinum element RTDs is MIL-C-5015 part number MS3102R-14S-7P, which is a three-pin receptacle that mates with plug part number MS3106F-14S-7S. See Figure 504–10–4 for RTD bare-bulb configuration construction.

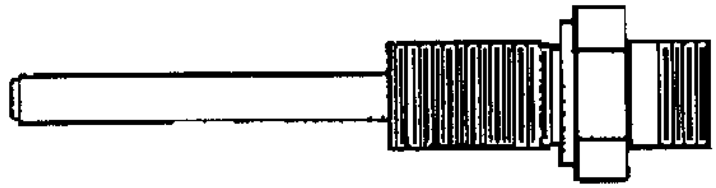


Figure 504-10-4. Bare-Bulb Configuration

504-10.4.5.3 Embedded Bearing Installations. The MIL-T-24388 RTD configuration for embedded installations in bearing applications requires the wire sensing element to be potted in a miniature can composed of tin-plated copper with a metal babbitt topping. The can dimensions are approximately 0.25 inch long with a diameter of 0.274 inch. The babbitt topping adds an additional 0.1 inch to the sensor's overall length. The babbitt topping is required to fuse the RTD into the babbitt lining of a bearing. The embedded RTD configuration requires a connection wire extension, at least three feet in length, to protrude from the back-end of the can. The extension wires are 24 gage, stranded copper with polymide insulation. See Figure 504–10–5 for RTD embedded configuration construction.

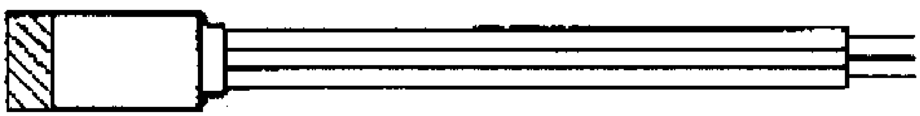


Figure 504-10-5. Embedded Configuration

504-10.4.5.4 Industrial-Grade RTDs. Industrial-grade RTDs that have qualified as a component of a ship system exist in the Fleet. Design and material construction of these RTDs may vary from the MIL-T-24388 sensors previously described.

504-10.4.5.5 RTD Monitoring Circuits. The electronic circuit that monitors the electrical resistance of an RTD is based on a Wheatstone bridge circuit. A two-wire RTD element is attached as one of the four resistance arms of a Wheatstone bridge circuit. The output voltage of the bridge circuit is a function of the varying electrical resistance on the arm containing the RTD. A compensation circuit is required in a two-wire RTD monitoring circuit to negate the added resistance of the interconnection cable leads between the RTD and the monitoring circuit. The compensation circuit consists of a voltage source that can be tuned to negate the voltage dropped on the sensor's arm of the bridge as a result of current flowing through the interconnection cable leads.

504-10.4.5.6 Three-Wire RTD Element. A three-wire RTD element can be connected to a Wheatstone bridge circuit in a manner that a compensation circuit is not required to negate the electrical resistance resulting from the interconnection cable. The resistance of the interconnection cable leads effectively cancels out in relation to the bridge output voltage when two leads are attached in opposite arms of one side of the bridge circuit. The additional common lead is connected directly to the bridge voltage output so that its resistance is negligible and appears as a virtual short when the bridge output is monitored by a circuit with a high input resistance. In other words, a negligible voltage drop will occur on the common lead and therefore the bridge output voltage strictly a function of the fixed resistors and the RTD on the bridge arms.

504-10.4.5.7 Single-Channel Temperature Monitors. Single-channel resistance thermometer systems for shipboard machinery applications consist of a MIL-T-24388 RTD installed in a MIL-T-24270 thermowell, MIL-C-24643 or MIL-C-915 interconnection cable, a MIL-T-24387 signal conditioner, and at least one MIL-M-16304 panel meter. The MIL-T-24387 RTD signal conditioner provides a linear 4 to 20 milliamp direct current output which is proportional to the temperature measurement span. The signal conditioner can be configured with an internal relay that changes state at a field-selectable temperature setpoint. MIL-M-16034, type KX-241 panel meters for this configuration have a 4.5 inch square case with a 250 degree scale arc based on full scale deflection over a 4 to 20 milliamp direct current input range.

504-10.4.5.8 Multi-Channel Temperature Monitors. Multi-channel resistance thermometer systems for shipboard machinery applications consist of MIL-T-24388 RTDs, MIL-C-24643 or MIL-C-915 interconnection cable, and a MIL-T-15377 temperature monitoring and alarm panel. The majority of temperature monitoring panels have been qualified over the years to several revisions of MIL-T-15377. The technical manual for the monitoring panel should be reviewed to determine if the system is compatible with platinum or nickel, two-wire or three-wire RTDs. MIL-T-15377 panels have the RTD signal conditioning circuitry built into modules, which mount into the front face of the panel. RTD signal conditioning modules are configured to provide monitoring and alarm functions for either two or four RTDs. The RTD modules are supported in the MIL-T-15377 panel by a power supply module, a meter module and an alarm module. A high or low temperature alarm condition causes a lamp on the affected RTD module to illuminate and a bell or a tone speaker on the alarm module will sound. The panel may also contain a set of relays, which can drive remote alarms when a monitoring channel reaches an alarm status.

504-10.4.5.9 Temperature Monitoring and Alarm Panel. A new multi-channel resistance thermometer system that has recently been introduced into the Fleet is built and tested in accordance with MIL-T-15377F and Electric Boat Specification 2927C. This temperature monitoring and alarm panel is capable of monitoring up to 60 sensors, including three-wire nickel and platinum RTDs and types J, K and T thermocouples. Printed circuit cards mounted inside the bulkhead mounted panel can monitor up to four of one sensor type. The panel has a three-digit display for indicating the present temperature or pre-set alarm setpoint temperature for any of the 60 channels. The front panel display assigns each measurement channel with a green lamp that illuminates when the channel temperature is currently being displayed and a red lamp that illuminates when the channel alarm setpoint has been achieved. The panel contains a pair of internal relays to perform remote alarm functions if required. The front panel has push-button and toggle switches to display channel and alarm setpoint temperatures, changing alarm setpoint temperatures and acknowledging alarms.

504-10.4.6 CONSOLE-BASED TEMPERATURE MONITORS. Console-based temperature monitors. Gas turbine powered ships predominantly have RTD monitoring circuits installed inside machinery control consoles. These circuits are packaged in the form of modular printed circuit boards or standard electronic module (SEM) cards that mount in the backplane of the console. Each circuit board or SEM card typically monitors four or more RTDs.

504-10.4.7 INTERCONNECTION CABLE. Interconnection cable. The interconnection cable appropriate for two-wire RTD systems is qualified to MIL-C-24643/33, type LS2SWU-X where the variable ″X″ represents the number of conductor pairs (i.e. X = 1, 3, 7, 12, 19, 24, 30, 37 or 61). The interconnection cable appropriate for three-wire RTD systems is qualified to MIL-C-915/8, type TSS-4 (Single triad) or MIL-C-24643/36, type LS3SWU-X (Multi-triad) where the variable ″X″ represents the number of conductor triads (i.e. X = 3, 7, 10, 14, 19, 24, 30 or 37). These cables consist of individually shielded, stranded copper conductor triads designed for watertight service.

504-10.4.8 PYROMETER. A pyrometer temperature measuring system consists of a sensor, a current or voltage measuring electronic device, and an electrical interconnection cable to connect the two components.

504-10.4.9 THERMOCOUPLES. The sensor, or thermocouple, in a pyrometer system is based on two dissimilar metal wires fused at one end to form a measurement junction.

504-10.4.10 MILITARY-GRADE THERMOCOUPLES. MIL-T-24388 specifies the construction and testing requirements for military-grade thermocouples which are generally required in high pressure steam applications for remote temperature monitoring and alarm capability. The MIL-T-24388 thermocouple is based on a type K sensing element, which has a measurement junction consisting of chromel and alumel wires. MIL-T-24388 thermocouples are specifically designed to mount in MIL-T-24270 thermowells. The thermocouple's measurement junction is housed in a closed-end metal tube or sheath with a 0.25-inch diameter. A compound similar to sand is packed in between the metal sheath and the dissimilar metal wires to act as an electrical insulator and to protect the measurement junction from mechanical stresses. The metal sheath is designed to compress against the bottom of a thermowell as a result of a spring and washer assembly at the opposite end of the sheath where it is affixed to a connection head. MIL-T-24388 thermocouples have standard sheath insertion lengths of 2.71 and 4.71 inches. The thermocouple has a connection head with a removable cap and a stuffing tube port to allow access to a terminal block which provides electrical terminals for the interconnection cable leads. A threaded pipe extension resides over the portion of the sheath between the thermowell and connection head to perform the function of rigidly mating the two components. The threaded pipe extension is available in lengths from 1.75 to 7 inches to ensure access to the thermocouple connection head when pipe lagging is present. The color coding and polarity designations for the dissimilar metal wires in a type K thermocouple are yellow (+) for chromel and red (-) for alumel. Refer to MIL-T-24388 for millivolt versus temperature calibration tables for these thermocouples.

504-10.4.11 INDUSTRIAL-GRADE THERMOCOUPLES. Several ship systems in the Fleet have been qualified with industrial-grade thermocouples. These thermocouples do not require thermowells since they are installed in low pressure systems that allow a direct immersion installation. Design and material construction of these thermocouples may vary from the descriptions for MIL-T-24388 units in this section. Industrial-grade thermocouples in the Fleet may be constructed with type K, J or T sensing elements. The dissimilar metals that comprise a type J measurement junction are iron and constantan. The color coding and polarity designations for type J thermocouple wires are white (+) for iron and red (-) for constantan. The dissimilar metals that comprise a type T measurement junction are copper and constantan. The color coding and polarity designations for type T thermocouple wires are blue (+) for copper and red (-) for constantan.

504-10.4.12 THERMOCOUPLE MONITORING CIRCUITS. Thermocouple sensors are monitored in a pyrometer system by either a current or voltage measuring circuit.

504-10.4.12.1 A pyrometer that employs a current measuring circuit is a self-powered system since it requires no external power supply and relies strictly on the millivolt potential generated in the thermocouple circuit. This type of pyrometer can only function properly when the combined electrical resistance of the thermocouple, interconnection cable leads and an adjustable calibration resistor is fixed (e.g. 10 ohms). A current-driven meter provides temperature indications based on the fixed resistance of the thermocouple circuit assembly and the predictable millivolt potential generated by the thermocouple.

504-10.4.12.2 A thermocouple can also be monitored by a voltage measuring circuit. The millivolt potential generated in the thermocouple circuit is amplified and then converted to a 4 to 20 milliamp direct current, which is linearly proportional to the temperature measurement range. The direct current output can drive one or more panel meters connected in series to create a current loop for repeating temperature indications.

504-10.4.13 TEMPERATURE COMPENSATION. Pyrometers require a temperature compensation circuit to ensure that the temperature at the reference junction of the thermocouple circuit does not introduce error into the measurement as ambient temperature changes. The reference junction of a thermocouple circuit is extended from the thermocouple head to the monitoring circuit when the interconnection cable wires are constructed of the same metals as the thermocouple sensor. The thermocouple circuit generates a millivolt potential proportional to the temperature differential between the dissimilar metal junction in the thermocouple sensor and the reference junction at the electronic monitoring circuit. The thermocouple sensor junction is also referred to as the hot junction and the reference junction is the cold junction based on the typical temperature at each junction. The self-powered, current-measuring type pyrometer relies on a factory preset, bimetallic spiral component built into the coil spring movement of the indicating meter. The bimetallic component ensures by mechanical means that ambient temperature changes at the reference junction do not affect measurement accuracy. The voltage-measuring type pyrometer relies on a circuit to simulate a constant reference junction temperature of 32°F. This type of compensation circuit is also known as a electronic ice point reference. A compensation voltage created by a temperature sensitive resistor in a voltage divider adds the necessary millivolt potential to the thermocouple circuit to account for a constant reference junction temperature of 32°F and not a variable ambient temperature.

504-10.4.14 SINGLE-CHANNEL PYROMETERS. Single-channel pyrometer systems for applications requiring a military-grade configuration consist of a MIL-T-24388 type K thermocouple installed in a MIL-T-24270 thermowell, MIL-C-24643 interconnection cable, a MIL-T-24387 signal conditioner, and at least one MIL-M-16304 panel meter. The MIL-T-24387 signal conditioner is a voltage-measuring type circuit, mounted in an electrical junction box, which provides a linear 4 to 20 milliamp direct current output proportional to the measurement span. The signal conditioner can be configured with an internal relay, which changes state at a field-selectable temperature setpoint. MIL-M-16034, type KX-241 panel meters for this configuration have a 4.5 inch square case with a 250 degree scale arc based on full scale deflection over a 4 to 20 milliamp direct current input range.

504-10.4.15 MULTI-CHANNEL PYROMETERS. Pyrometer systems capable of multi-channel monitoring are predominantly used in the Fleet to measure cylinder exhaust temperatures in diesel engine propulsion and generator applications. These pyrometers are qualified as part of the ship system and primarily consist of industrial-grade components. The multi-channel pyrometers in the Fleet are based on a self-powered, current-measuring circuit as previously described. A panel-mounted, metal enclosure houses the channel selector switch and the current-driven, analog meter, which displays temperature. The most common multi-channel, self-powered pyrometer that monitors type J thermocouples is the Alnor 2670E. Channel selector switches for this pyrometer are available with 8, 17 and 35 channels. Multi-channel pyrometers in the Fleet may be configured with either one adjustable calibration resistor per pyrometer or one resistor per measurement channel. A pyrometer with a single calibration resistor connected to the channel selector switch operates optimally when the interconnection wires to each individual thermocouple have the identical length. That is, a pyrometer based on a current-measuring circuit requires each thermocouple circuit to have a fixed resistance to operate correctly.

504-10.4.16 CONSOLE-BASED PYROMETERS. Control consoles can also house thermocouple monitoring circuits, which are packaged in the form of electronic modules or cards that mount in the backplane of the console. These signal conditioning devices monitor thermocouple sensors with voltage measuring circuits.

504-10.4.17 INDUSTRIAL-GRADE PYROMETERS. Industrial-grade, single-channel pyrometer systems in the Fleet are primarily self-powered and are based on a current-measuring, fixed-resistance circuit.

504-10.4.18 INTERCONNECTION CABLE. The interconnection cable which connects the thermocouple to the electrical measuring circuit must contain conductors composed of the same metals as the type of thermocouple employed. Thermocouple interconnection cable is qualified to MIL-C-24643/21 (Single pair) or /24 (Multi-pair). The cable designations are LSTCJU and LSTCJX for type J cable, LSTCKX for type K cable and

LSTCTU and LSTCTX for type T cable. This specification requires the cable to be low-smoke, watertight and armored with 1, 3, 7 or 12 pairs of thermocouple wires. The color coding and polarity designations for MIL-C-24643/21 single-pair cables are gray (+) for iron and red (-) for constantan (LSTCJU-4; type J thermocouples) and blue (+) for copper and red (-) for constantan (LSTCTU-4; type T thermocouples). The color coding and polarity designations for MIL-C-24643/24 multi-pair cables (LSTCJX, LSTCKX, and LSTCTX) can be misleading because they are identical for all three types of thermocouples. The constantan or alumel lead for every pair of thermocouple wires will always be red (-). The positive iron, chromel or copper lead for the thermocouple wire pairs is color-coded as follows: white (#1), black (#2), green (#3), orange (#4), blue (#5), white/black (#6), white/green (#7), white/orange (#8), white/blue (#9), white/red (#10), black/white (#10), and green/white (#12).

## 504-10.5 OPERATION

504-10.5.1 LIQUID-IN-GLASS THERMOMETERS. Laboratory and medical thermometers constructed in accordance with the ASTM E-1 are typically used for analytical testing of fuel, oil and water. A comprehensive listing of ASTM thermometers by temperature range and scale graduations is provided in the E-1 standard.

504-10.5.1.1 Performance. A variety of temperature measurement ranges for ASTM E-1 thermometers are available within the span of -102 to 760°F. Scale graduations vary from 0.05 to 5°F. Accuracy of liquid-in-glass thermometers is generally specified to be within one-half of the smallest scale division.

504-10.5.1.2 Installation. ASTM E-1 thermometers must be immersed to the proper depth in a liquid in order to maximize its accuracy. The proper immersion line is etched on the stem of the thermometer.

504-10.5.1.3 Liquid-In-Glass Thermometers. Liquid-in-glass thermometers are designed to provide optimal measurement accuracy when immersed in a vertical position in the fluid being monitored.

504-10.5.2 BIMETALLIC THERMOMETERS. Bimetallic thermometers constructed in accordance with MIL-T-17244 are designed for single-point, direct-reading temperature indications requiring thermowell installations in machinery applications.

504-10.5.2.1 Performance. The standard measurement ranges for these thermometers are as follows: -40 to 180°F, 20 to 240°F, 50 to 550°F and 50 to 750°F. The measurement range is selected so that the maximum normal system operating temperature is approximately 75 percent of the full scale range and system operating temperatures are in the middle third of the scale range. Measurement accuracy is one percent of full span for these thermometers. The accuracy of the temperature measurement is also a function of how the observer views the instrument. The observer’s line-of-sight should be perpendicular to the indicating pointer at its center.

504-10.5.2.2 Installation. Thermowell material selection and installation methods for bimetallic thermometers must strictly adhere to the practices stated in NAVSHIPS Drawing 810-1385917.

504-10.5.2.2.1 Thermowells installed in systems with operating temperature above 400°F should be positioned vertically to prevent gradual sagging of the protective tube.

504-10.5.2.2.2 Thermowell location should be selected to ensure adequate flow of the measured fluid around the protective tube. Avoid thermowell installations in stagnant areas, air pockets or positions, which will not provide a true temperature indication of the medium being monitored.

504-10.5.2.2.3 Selection of the thermometer's stem length should be based on the goal of positioning the tip of the stem in the center of the flow being monitored. Thermometers with elongated stem lengths are required in pressure vessel applications in which the center cannot feasibly be reached by the stem.

504-10.5.2.2.4 Thermometer location should be selected to ensure ease of temperature observation and to minimize potential for accidental breakage.

504-10.5.2.2.5 MIL-T-17244 magazine type thermometers are required for installations in each magazine, ammunition, pyrotechnic and weapons storage space. Unless otherwise specified, magazine thermometers shall be mounted in an L-shaped bracket built to the specifications of NAVSHIPS Drawing 810-1385917 and attached to a supporting structure. Where the installation of the thermometer interferes with stored material or equipment, the thermometer shall be mounted in a boss on the outside of the magazine with the sensing stem projecting inside the storage space.

504-10.5.3 FILLED-SYSTEM THERMOMETERS. Filled-system or gas actuated thermometers built and tested to MIL-T-19646 are designed for single-point, remote-reading temperature indications requiring thermowell or flange-mount installations in machinery applications.

504-10.5.3.1 Performance. The standard measurement ranges for MIL-T-19646 thermometers with a class C, thermowell mounted, sensor configurations are as follows: -40 to 180, 20 to 240°F, 50 to 400°F, 50 to 550°F, 50 to 750°F and 400 to 1200°F. The class A sensor configuration which is mounted in a bracket for air temperature measurements has a range of -40 to 180°F. The class B sensor configuration which is intended to replace mercury actuated thermometers in steam applications has measurement ranges of 50 to 750°F and 400 to 1200°F. Measurement range is selected so that the maximum normal system operating temperature is approximately 75 percent of the full scale range and system operating temperatures are in the middle third of the scale range. Measurement accuracy is one percent of full span for these thermometers. The accuracy of the temperature measurement is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer.

504-10.5.3.2 Installation. MIL-T-19646 remote-reading thermometers are required whenever installation of a direct-reading bimetallic thermometer would not be accessible for reading, calibration and maintenance.

504-10.5.3.2.1 Thermowell material selection and installation methods for filled-system thermometers with a class C sensor configuration must strictly adhere to the practices stated in NAVSHIPS Drawing 810-1385917.

504-10.5.3.2.2 Thermowell location should be selected to ensure adequate flow of the measured fluid around the protective tube. Avoid thermowell installations in stagnant areas, air pockets or positions which will not provide a true temperature indication of the medium being monitored.

504-10.5.3.2.3 Thermowells installed in systems with operating temperature above 400°F should be positioned vertically to prevent gradual sagging of the protective tube.

504-10.5.3.2.4 Filled-system thermometers with a class A sensor configuration are intended to be installed in a mounting bracket constructed in accordance with NAVSEA Drawing 810-1385917.

504-10.5.3.2.5 The thermometer's capillary extension should remain coiled until installation to reduce potential for damage.

504-10.5.3.2.6 Do not handle or carry the thermometer by suspending the sensing bulb or indicator case by the capillary extension. Damage to the capillary extension may lead to loss of the instrument's fill fluid or gas.

504-10.5.3.2.7 The installation distance between the readout gage and the sensing bulb is typically limited to the maximum allowable capillary extension length of 125 feet, unless otherwise specified.

504-10.5.3.2.8 The thermometer's indicator case should be installed in the same compartment as the sensing bulb and capillary extension whenever possible. Also, surplus capillary should be coiled and supported near the indicator case. Variation in temperature between the capillary and the indicator case will introduce error in the temperature measurement.

504-10.5.3.2.9 Avoid installation if the capillary extension and the indicator case near sources of heat or cold. Variation in temperature between the capillary and the indicator case will introduce error in the temperature measurement.

504-10.5.3.2.10 Selection of the thermometer's stem length should be based on the goal of positioning the tip of the stem in the center of the flow being monitored. Thermometers with elongated stem lengths are required in pressure vessel applications in which the center of the flow stream cannot feasibly be reached by the stem.

504-10.5.3.2.11 Thermometer location should be selected to ensure ease of temperature observation and to minimize potential for accidental breakage.

504-10.5.4 RESISTANCE THERMOMETERS. Resistance thermometer systems are designed for machinery applications requiring remote-reading, single- or multi-point temperature monitoring and alarm capabilities. Resistance thermometers are typically installed to monitor systems with operating temperatures between -40 and 400°F, although accurate measurements up to 1000°F are possible when platinum RTDs are employed. There are three RTD sensor configurations specified in MIL-T-24388 to support different types of applications in the Fleet.

504-10.5.4.1 MIL-T-24388 Thermowell. The MIL-T-24388 thermowell configuration is designed for applications where either a penetration into a high pressure vessel is necessary or when the response time of the temperature measurement is not extremely critical. Use of a thermowell slows the response of a sensor since the heat must conduct through the well material. The advantage of a thermowell installation over direct immersion is that the sensor can be removed for maintenance without disturbing the pressure boundary of the system.

504-10.5.4.1.1 The MIL-T-24388 RTD bare-bulb configuration is designed for applications where a sensor must be directly immersed in a high pressure gas in order to respond more rapidly to changes in temperature than the slower responding thermowell configuration. Bare-bulb RTD installations are primarily employed in high pressure air compressor applications to monitor temperatures of air at several compressor stages, crankcase oil, and cooling water.

504-10.5.4.1.2 The MIL-T-24388 RTD embedded configuration is designed for monitoring oil film temperatures in machinery bearing applications such as generators, propulsion shafts, and main reduction gears.

504-10.5.4.2 Performance. The performance criteria for resistance thermometers in the Fleet is based on the individual components selected. The performance specifications for the various components qualified for resistance thermometer configurations are stated below.

504-10.5.4.2.1 Nickel-element RTDs. MIL-T-24388 RTDs configured with nickel elements for thermowell, bare-bulb or embedded installations have a measurement range of -40 to 400°F. The measurement accuracy for a nickel sensing element is ± 2°F from -40 to 200°F and ± 1% of the indicated temperature measured from 200 to 400°F. A table, which provides the resistance versus temperature data for the sensor's calibration curve is provided in MIL-T-24388. The sensor is commonly referred to as a 120 ohm nickel RTD, which is the element's electrical resistance at 32°F.

504-10.5.4.2.2 Platinum-element RTDs. MIL-T-24388 RTDs configured with platinum elements for thermowell and bare-bulb installations have a measurement range of -40 to 1000°F. Platinum RTDs for embedded installations have a measurement range of -40 to 400°F. The measurement accuracy for a platinum sensing element is ± 2°F from -40 to 530°F and ± 0.375% of the indicated temperature measured from 530 to 1000°F. A table that provides the resistance versus temperature data for the sensor's calibration curve is provided in MIL-T-24388. The sensor is commonly referred to as a 100-ohm platinum RTD, which is the element's electrical resistance at 32°F.

504-10.5.4.2.3 Industrial-grade RTDs. Industrial-grade RTDs that have qualified as a component of a ship system have similar measurement ranges but are typically less accurate than MIL-T-24388 sensors which have reference-grade sensing elements that have minimal metal impurities. Impurities in the platinum or nickel element affect the linearity of the resistance versus temperature calibration curve.

504-10.5.4.2.4 Single-channel temperature monitors. Single-channel resistance thermometer systems which require a military specification installation consist of a MIL-T-24388 RTD installed in a MIL-T-24270 thermowell, MIL-C-915 interconnection cable, a MIL-T-24387 signal conditioner, and MIL-M-16304 panel meter(s). MIL-T-24387 single-channel resistance thermometer systems have the RTD signal conditioning circuitry mounted in an electrical junction box. The standard ranges for MIL-T-24387 RTD signal conditioners are the following: -40 to 260°F, 0 to 400°F, 0 to 700°F and 0 to 1000°F. The measurement range is selected so that the maximum normal system operating temperature is approximately 75 percent of the full scale range and system operating temperatures are in the middle third of the scale range. The measurement accuracy of the direct current output for MIL-T-24387 signal conditioners is + 1% of full span. The accuracy of the MIL-M-16304 panel meter is 1.5% of measurement span. The accuracy of the temperature measurement is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer at its center. Remember that the accuracy of the RTD sensor should be taken into consideration when calculating the overall accuracy of the resistance thermometer.

504-10.5.4.2.5 Multi-channel temperature monitors. MIL-T-15377D multi-channel temperature monitoring and alarm panels are manufactured by Marine Electric Corporation, Pickard & Burns, Inc. and Thomas Edison Industries, Inc. The common measurement ranges for these resistance thermometer systems are 0 to 300°F, 100 to 400 and 0 to 400°F. Measurement accuracy of these panels is typically + 2% of mid-range value (0 to mid-range) and + 2% of readout (mid-range to full scale). Panels built by Eaton Corporation have a measurement range of 0 to 400°F and a measurement accuracy of + 1% full scale. The accuracy of the temperature measurement on an analog readout is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer at its center. Temperature monitoring and alarm panels built to MIL-T-15377F and Electric Boat Specification 2927C by Hy-Cal and Henschel Corporations also exist in the Fleet. The measurement range for either of these systems is 0 to 800°F, although the upper end of the range is limited to

400°F when nickel-element RTDs are employed. Measurement accuracy of these panels is + 2% of mid-range value. Remember that the accuracy of the RTD sensor should also be taken into consideration when calculating the overall accuracy of the resistance thermometer.

504-10.5.4.2.6 Console-based temperature monitors. Control consoles for propulsion and electric plants in the Fleet have RTD monitoring circuits packaged in the form of modular printed circuit boards or standard electronic module (SEM) cards that mount in the backplane of the console. Console signal conditioners are typically designed to monitor platinum RTDs throughout a measurement range of -40 to 500°F. The measurement accuracy is generally + 1.5 to 2% of span with a readout resolution of 1°F. The accuracy of the RTD sensor should also be taken into consideration when calculating the overall accuracy of the resistance thermometer. Refer to the console technical manual for measurement range and accuracy criteria for the specific circuit card.

504-10.5.4.3 Installation.

504-10.5.4.3.1 Thermowells installed in systems with operating temperature above 400°F should be positioned vertically to prevent gradual sagging of the protective tube.

504-10.5.4.3.2 Thermowell location should be selected to ensure adequate flow of the measured fluid around the protective tube. Avoid thermowell installations in stagnant areas, air pockets or positions, which will not provide a true temperature indication of the medium being monitored.

504-10.5.4.3.3 Selection of the thermometer’s stem length should be based on the goal of positioning the tip of the stem in the center of the flow being monitored. Thermometers with elongated stem lengths are required in pressure vessel applications in which the center cannot feasibly be reached by the stem.

504-10.5.4.3.4 Installation of an embedded RTD in a bearing is generally performed by the bearing manufacturer or at a shipyard facility. A description of the installation procedure for embedding MIL-T-24388 RTDs into a bearing is provided in MIL-HDBK-298 (Selection, Installation and Troubleshooting of Resistance Thermometers and Thermocouple Sensors). In general, the RTD is inserted in a pre-drilled hole in the bearing so that the sensor’s babbitt topping can be heated with a propane torch and ultimately fuse the sensor with the babbitt lining of a bearing. The three foot connection wire extension protruding from the back-end of the sensor is potted with epoxy in a channel on the outside perimeter of the bearing. The extension wire conductors are then soldered to the tin-plated brass terminals of a MIL-T-17600 circular terminal block. The terminal block has a teflon body which is epoxied to the outer perimeter of the bearing. An intermediate connection cable provides an electrical connection between the terminal block and a military-grade connector, which is mounted on the outer surface of the bearing housing or reduction gear casing. A standard copper interconnection cable then completes the resistance thermometer circuit between the military-grade connector and the temperature monitoring panel or control console.

504-10.5.5 PYROMETERS. Pyrometer systems are designed for machinery applications requiring remote-reading, single- or multi-point temperature monitoring capabilities. These thermometers are primarily installed to monitor systems that have fluids and gases at operating temperatures between 0 to 1200°F. The primary applications for pyrometers include engine and generator gas temperatures, boiler superheater outlet temperatures and catapult accumulator temperatures. The performance specifications for the various components are stated below.

504-10.5.5.1 Performance.

504-10.5.5.1.1 Type K Thermocouples. MIL-T-24388 type K (chromel/alumel) thermocouples are configured for MIL-T-24270 thermowell installations. Type K thermocouples have a measurement range of -40 to 1500°F with a measurement accuracy of ± 2°F from -40 to 530°F and ± 0.375% of the indicated temperature measured from 530 to 1500°F. A table which provides the millivolt versus temperature data for the sensor's calibration curve is provided in MIL-T-24388.

504-10.5.5.1.2 Industrial-Grade Thermocouples. Industrial-grade thermocouples that have qualified as a component of a ship system are typically less accurate than MIL-T-24388 sensors. Systems requiring exhaust gas temperature measurements are generally instrumented with type J thermocouples to cover a range of 0 to 1200°F. Systems requiring temperature measurement of cryogenic liquids and gases have been instrumented with strap-on, type T thermocouples for a range of -300 to 750°F.

504-10.5.5.1.3 Single-Channel Pyrometers. Single-channel pyrometer systems which require a military specification installation for high pressure vessels consist of a MIL-T-24388 type K thermocouple installed in a MIL-T-24270 thermowell, MIL-C-24643 interconnection cable, a MIL-T-24387 signal conditioner, and MIL-M-16304 panel meter(s). The MIL-T-24387 signal conditioner is a solid-state, voltage-measuring type circuit mounted in an electrical junction box. The signal conditioner is a direct current output of 4 to 20 milliamp that can drive remote panel meter(s) connected in a series circuit. The standard ranges for MIL-T-24387 thermocouple signal conditioners are the following: 0 to 400°F, 0 to 700°F, 0 to 1000°F, 400 to 1200°F and 500 to 1500°F. Measurement range is selected so that the maximum normal system operating temperature is approximately 75 percent of the full scale range and system operating temperatures are in the middle third of the scale range. The accuracy of the direct current output for MIL-T-24387 signal conditioners is + 1% of measurement span. The accuracy of the MIL-M-16304 panel meter is 1.5% of measurement span. The accuracy of the temperature measurement for an analog readout is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer at its center. Remember that the accuracy of the thermocouple sensor should also be taken into consideration when calculating the overall accuracy of the pyrometer.

504-10.5.5.1.4 Industrial-Grade Pyrometers. Industrial-grade, single-channel pyrometer systems that consist of a current-measuring circuit that requires a calibration resistor to ensure a fixed resistance of the thermocouple sensor and cable have been installed in the Fleet. These pyrometer systems are self-powered by the thermocouple sensing voltage as described above and are packaged as a commercial-grade panel meter. The accuracy of the temperature measurement for an analog readout is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer at its center. Remember that the accuracy of the thermocouple sensor should also be taken into consideration when calculating the overall accuracy of the pyrometer.

504-10.5.5.1.5 Multi-Channel Pyrometers. Multi-channel pyrometer systems are predominantly used in the Fleet to measure cylinder exhaust in diesel engine and generator applications. These pyrometers are qualified as part of the ship system and are constructed with industrial-grade components. The multi-channel systems are based on a current-measuring circuit and may have a separate calibration resistor for each measurement channel for optimal accuracy. The most common multi-channel, self-powered pyrometer for use with bare-bulb, type J thermocouples is the Alnor 2670E. This unit has a measurement range of 0 to 1200°F with an accuracy of + 2% of measurement span. The accuracy of the temperature measurement for an analog readout is also a function of how the observer views the instrument. The observer's line-of-sight should be perpendicular to the indicating pointer at its center. Remember that the accuracy of the thermocouple sensor should also be taken into consideration when calculating the overall accuracy of the pyrometer. Channel selector switches are available with 8, 17 and 35 channels.

504-10.5.5.1.6 Console-Based Pyrometers. Control consoles and temperature monitoring and alarm panels can also house thermocouple monitoring circuits, which are packaged in the form of electronic modules or cards that are internally mounted. Refer to the console technical manual for measurement range and accuracy criteria for the specific circuit card.

504-10.5.5.2 Installation.

504-10.5.5.2.1 Thermowell material selection and installation methods for MIL-T-24388 type K thermocouples must strictly adhere to the practices stated in NAVSHIPS Drawing 810-1385917.

504-10.5.5.2.2 Thermowells installed in systems with operating temperature above 400°F should be positioned vertically to prevent gradual sagging of the protective tube.

504-10.5.5.2.3 Thermowell location should be selected to ensure adequate flow of the measured fluid around the protective tube. Avoid thermowell installations in stagnant areas, air pockets or positions that will not provide a true temperature indication of the medium being monitored.

504-10.5.5.2.4 Selection of the thermometer's stem length should be based on the goal of positioning the tip of the stem in the center of the flow being monitored. Thermometers with elongated stem lengths are required in pressure vessel applications in which the center cannot feasibly be reached by the stem.

504-10.5.5.2.5 Pyrometer system components should be installed in locations to ensure ease of temperature observation and to minimize potential for accidental breakage.

504-10.5.5.2.6 The thermocouple, interconnection cable and signal conditioner in a pyrometer system must all be matched for the same type of thermocouple (i.e. type J, K or T). Mismatching the metals in a pyrometer circuit will introduce additional dissimilar metal junctions that cannot be compensated for by the signal conditioner.

504-10.5.5.2.7 Maintaining the polarity or color code of the interconnection cable leads from the thermocouple to the signal conditioner is absolutely essential for accurate pyrometer measurements. Lead reversals will introduce additional dissimilar metal junctions that cannot be compensated for by the signal conditioner.

504-10.5.5.2.8 Do not use copper interconnection cables in pyrometer systems. Use of copper interconnection cable essentially moves the reference junction of the thermocouple circuit from the signal conditioner to the location where the copper leads meet the thermocouple leads. This practice will introduce an error into the pyrometer measurement if the ambient temperatures at the signal conditioner and the newly created reference junction are not identical. The error occurs because the signal conditioner has a temperature compensation circuit that is based on the ambient temperature present at the conditioner.

504-10.5.5.2.9 The use of connector pins and sockets made of thermocouple metals is only required when a connector assembly is not at a uniform temperature. Normally, a small connector contact would be at a uniform temperature in a thermocouple circuit and the dissimilar metal junctions created would cancel out. That is, the voltage created by a copper to alumel junction in series with an alumel to copper junction at the same temperature would cancel out. Thermocouple contacts for connectors are available but costly for situations where thermal gradients in the connectors are possible.

504-10.5.5.2.10 Signal conditioners and junction boxes in pyrometer systems should not be mounted near potential sources of heating or cooling to safeguard against temperature gradient errors where copper terminals or connector contacts are implemented in thermocouple circuits.

## 504-10.6 CARE AND MAINTENANCE

504-10.6.1 GENERAL. Recommended preventive maintenance procedures for all shipboard thermometers to be performed on a scheduled basis are provided in Planned Maintenance System (PMS) documentation. These maintenance procedures are outlined in the appropriate Maintenance Requirement Cards (MRCs) for the instrument and the application.

504-10.6.1.1 Both mechanical and electrical thermometers are generally maintenance free with the exception of periodic inspections to determine operational status, physical integrity and cleaning. Thermometer sensing sheaths, which are directly immersed in systems without thermowells, require routine cleaning to ensure thermal response is not inhibited by material build-up. The sheath should be reinstalled to the proper immersion length after it is cleaned.

504-10.6.1.2 Measures should be taken to keep debris from entering a thermowell when the sensor is removed. Debris in a well can cause the sensor sheath to seize in place, especially in high temperature applications. The use of lubricants or thermal conducting pastes in thermowells is not recommended in normal circumstances since these compounds will tend to attract debris.

504-10.6.2 LIQUID-IN-GLASS THERMOMETER. ASTM E-1 laboratory and medical thermometers should be handled with care and cleaned after each use for optimal performance.

504-10.6.3 BIMETALLIC THERMOMETER. The sensing element of a bimetallic thermometer can become damaged if exposed to overtemperature, shock or prolonged vibration. A damaged element could prohibit the indicating pointer from rotating smoothly or could result in a permanent shift in the measurement accuracy of the thermometers. A distorted sensing element cannot be repaired or replaced.

504-10.6.4 FILLED-SYSTEM THERMOMETER. The component most susceptible to damage in a filled-system thermometer is the capillary extension which connects the sensing bulb to the Bourdon tube indicating assembly. Breakage in a capillary extension will result in loss of the thermometer’s fill fluid or gas, which cannot be replaced by ship’s force. Care should be taken to prevent the capillary from kinking during installation and when dismounted for calibration or repair purposes.

504-10.6.5 RESISTANCE THERMOMETER. Resistance thermometer systems do not require any special care or maintenance other than the general directions for thermometers previously mentioned. An RTD is a non-repairable item and must be replaced if the resistance of the wire element is measured as an electrical open, short or not within the sensor’s allowable calibration tolerance.

504-10.6.6 PYROMETER. Pyrometer systems do not require any special care or maintenance other than the general directions for thermometers described above. The thermocouple is a non-repairable item and must be replaced if the resistance of the sensing element is measured as an electrical open or if the millivolt versus temperature curve is not within the sensor's allowable calibration tolerance.

## 504-10.7 CALIBRATION

504-10.7.1 GENERAL. Calibration procedures for thermometers in the Fleet have been documented in the following formats: Technical Manuals for Installed Instrumentation (for most surface ships), Planned Maintenance System Maintenance Requirement Cards (for submarines), **Technical Manual for Shipboard Gage Calibration Program Calibration Procedures** ST700-AS-PRO-010 or as a NAVAIR Instrument Calibration Procedure. Calibration intervals are assigned in accordance with the NAVSEA Metrology and Calibration Program and the Field Calibration Activity Metrology Requirements List.

504-10.7.2 LIQUID-IN-GLASS THERMOMETERS. Laboratory and medical thermometers constructed in accordance with ASTM E-1 can be submitted to a calibration facility, which has a fluid bath and a reference thermometer. These instruments can also be calibrated using the standards and methods described in paragraph 504-10.7.3.

504-10.7.3 BIMETALLIC THERMOMETERS. The calibration method for bimetallic thermometers is dependent on the stem size, which is either 2 or 4 inches long for MIL-T-17244 units. Thermometers with a stem size of 4 inches are calibrated with a portable, dry-well temperature calibrator. The common dry-well calibrators in the Fleet are the King Nutronics Model 3605-1-101 (Range: -40 to 250°F) and Model 3604-1-101 (Range: 100 to 1200°F). The thermometer indication is compared to the temperature setpoint of the dry-well calibrator at three points within the thermometer's measurement range. One point is in the lower third, a second point in the middle third and a third point in the upper third of the thermometer's measurement range. All three calibration measurements are required to be within ± 1% of the thermometer's measurement span in comparison to the setpoint temperature of the calibrator. The calibration procedure for these bimetallic thermometers is provided in the No Shipboard Gage Calibration Program Procedures Technical Manual ST700-AS-PRO-010, and NAVAIR Procedure No. 17-20ST-165 and 17-20ST-166.

504-10.7.3.1 Thermometers with a stem size of 2 inches cannot be effectively calibrated in a dry-well temperature because the thermometer's indicating case will tend to sink heat away from the relatively short sheath, resulting in an erroneously low temperature indication. Bimetallic thermometers with a 2 inch stem length require a fluid bath and a reference thermometer for proper calibration. The calibration requirements for thermometers with 2 and 4 inch stems are identical. The calibration procedure for the 2 inch stem bimetallic thermometers is provided in NAVAIR Procedure No. 17-20ST-02.

504-10.7.4 FILLED-SYSTEM THERMOMETERS. The calibration method for filled-system thermometers is dependent on the sensing bulb diameter and length. The King Nutronics Model 3605-1-101 (Range: -40 to 250°F) and Model 3604-1-101 (Range: 100 to 1200°F) dry-well temperature calibrators can be used to calibrate thermometers in the field only if the sensing bulb is limited in physical size to a maximum diameter of 1 inch and a maximum length of 5 inches. The thermometer indication is compared to the temperature setpoint of the dry-well calibrator at three points within the thermometer's measurement range. One point is in the lower third, a second point in the middle third and a third point in the upper third of the thermometer's measurement range. All three calibration measurements are required to be within + 1% of the thermometer's measurement span in comparison to the setpoint temperature of the calibrator. The calibration procedure for these filled-system thermometers is provided in the Shipboard Gage Calibration Program Procedures Technical Manual No. ST700-AS-PRO-010 and NAVAIR Procedure No. 17-20ST-165 and 17-20ST-166.

504-10.7.4.1 Filled-system thermometers with stem sizes beyond the physical limitations of the King Nutronics series of dry-well temperature calibrators must be dismounted from their system installations and transported to a calibration facility which has either a fluid bath or a environmental chamber and a reference thermometer. The calibration procedure for these filled-system thermometers is provided in NAVAIR Calibration Procedure No. 17-20ST-93.

504-10.7.5 RESISTANCE THERMOMETERS. The calibration methods for the various configurations of resistance thermometers in the Fleet are provided in the Technical Manual for Installed Instrumentation System Calibration Procedures for the specific surface ship or class. Calibration procedures for submarine applications are provided in the Planned Maintenance System Maintenance Requirement Card for the specific equipment. The initial step of a resistance thermometer calibration procedure involves verifying that all channels are operating at ambient temperature. If the thermometer appears to be operational, the RTD sensor is assumed to be functional and is replaced during the procedure with a resistance decade box to conveniently simulate three temperature points and to verify the alarm setpoint if applicable in the thermometer's measurement range. One calibration point is in the lower third, a second point in the middle third and a third point in the upper third of the thermometer's measurement range. The calibration tolerances and signal conditioner adjustments for each specific thermometer are provided in the appropriate calibration procedure. If the resistance thermometer appears to be inaccurate at ambient temperature after the calibration procedure has been completed, the operational status of the RTD sensor can be verified in a King Nutronics Model 3605-1-101 dry-well temperature calibrator. The resistance thermometer accuracy should be checked at the mid-range, or otherwise specified, temperature to determine if the RTD sensor has been damaged or if a shift in its calibration curve occurred. Embedded bearing RTDs should be replaced if they appear to have failed or if a erroneous shift in the calibration curve is suspected. The RTD sensor should be replaced and the one-point accuracy check in the dry-well calibrator repeated with a new sensor if necessary.

504-10.7.6 PYROMETERS. The calibration methods for the various configurations of pyrometers in the Fleet are provided in the Technical Manual for Installed Instrumentation System Calibration Procedures for the specific surface ship or class. Calibration procedures for submarine applications are provided in the Planned Maintenance System Maintenance Requirement Card for the specific equipment. The initial step of a pyrometer calibration procedure involves verifying that all channels are operating at ambient temperature. If the pyrometer appears to be operational, the thermocouple sensor is assumed to be functional and is replaced during the procedure with a thermocouple simulator which is a calibrated millivolt source that is used to conveniently simulate three temperature points and to verify the alarm setpoint, if applicable, in the pyrometer's measurement range. One calibration point is in the lower third, a second point in the middle third and a third point in the upper third of the thermometer's measurement range. The calibration tolerances and signal conditioner adjustments for each specific pyrometer are provided in the appropriate calibration procedure. If the pyrometer appears to be inaccurate at ambient temperature after the calibration procedure has been completed, the operational status of the thermocouple sensor can be verified in a King Nutronics Model 3605-1-101 dry-well temperature calibrator. The pyrometer accuracy should be checked at the mid-range or otherwise specified temperature to determine if the thermocouple sensor has been damaged or if a shift in its calibration curve occurred. The thermocouple sensor should be replaced and the one-point accuracy check in the dry-well calibrator repeated with a new sensor if necessary.

504-10.7.6.1 Pyrometers and thermocouples can also be calibrated using the Ectron 1100CF Thermocouple Simulator-Calibrator. The 1100CF can simulate thermocouple types E, J, K and T. This simulation covers the entire temperature range given for each of these types in degrees Celsius or Fahrenheit. In either case, the temperature can be set to within 0.1 degree by adjusting five lever (thumbwheel) switches. Complete calibration procedures are provided in NAVAIR Calibration Procedure No. 17-20ST-174 and 17-20ST-172, respectively.

# SECTION 11.
# TACHOMETERS

## 504-11.1 ENGINEERING PRINCIPLES

504-11.1.1 GENERAL DESCRIPTION. A tachometer is an instrument capable of generating, transmitting, and indicating information (or a signal) that can be converted into a measurement of rotational speed. Rotational speed is the number of revolutions for each unit of time, commonly measured in revolutions per minute (r/min). Measurements of rotary speed are made for a variety of purposes on many kinds of machines. Usually, more than one type of instrument or method would serve equally well for a particular case. Tachometers are generally classified as either portable (handheld) or fixed (continuous duty) instruments.

504-11.1.2 EQUIPMENT APPLICATION. Portable handheld types are used for intermittent tests on various machines. They also serve as a backup speed verification for use in testing speed limiting governors and overspeed trips. Fixed types, permanently installed, are used if continuous separate indications are needed. They are used to monitor shaft rotation on rotating machinery such as gas generators, power turbines, main propulsion shafts, main feed pumps, ships service turbine generators and forced draft blowers. Linear velocity may be measured with tachometers by using suitable adapters and conversion factors.

## 504-11.2 DEFINITION

504-11.2.1 INSTANTANEOUS SPEED. Instantaneous speed is the limit of the average speed as the period of time approaches zero.

504-11.2.2 VARIABLE RELUCTANCE. Variable reluctance is the variation of the resistance of flow of the magnetic field which dynamically changes the magnetic field strength.

504-11.2.3 GENERATOR. The element in which ac voltage is generated by virtue of relative motion with respect to a magnetic field.

504-11.2.4 ACTUATOR. A mechanism used for moving or actuating another device.

504-11.2.5 OPTO-ELECTRONICS UNIT. The opto-electronics unit performs all electronic functions to convert the optical signal received from the sensor head to a electrical or optical signal corresponding to the shaft speed.

## 504-11.3 SAFETY

504-11.3.1 ROTATING EQUIPMENT PRECAUTIONS. As with any rotating machinery, pins and projections liable to catch clothing should be eliminated or covered. Connecting gears should be securely covered to protect both personnel and the gears. Portable tachometers should be held firmly and applied as described in paragraph . Operating personnel should never use a portable tachometer in a place or manner requiring that they lean over or reach into rotating machinery.

504-11.3.2 MULTIPLE RANGE OR MULTIPLE SCALE TACHMETERS. Navy policy is to eliminate multiple range and multiple scale tachometers because of the probability of misinterpretation of the actual speed of rotation by operating personnel inadvertently reading the wrong scale. Elimination of multiple range and multiple scale tachometers will require a period of time, and both single and multiple scale and range instruments will be in the fleet. In order to alert user personnel to limitations on the use of multiple range and multiple scale tachometers, each multiple range and multiple scale tachometer shall have affixed a NOTICE tag in accordance with Figure 504-11-1. When multiple range and multiple scale tachometers are being used, it is imperative that the correct range setting and scale for the rotation to be measured be verified and used. Overspeed conditions can result from improper interpretation of scale readings or settings. When using tachometers for testing turbines and generators, only single range, single scale tachometers shall be used. At least two independent methods of verifying turbine speed shall be used to calibrate the overspeed trip device. Portable tachometers shall have the applicable tag attached in accordance with **NSTM Chapter 491, Electrical Measuring and Test Instruments** .

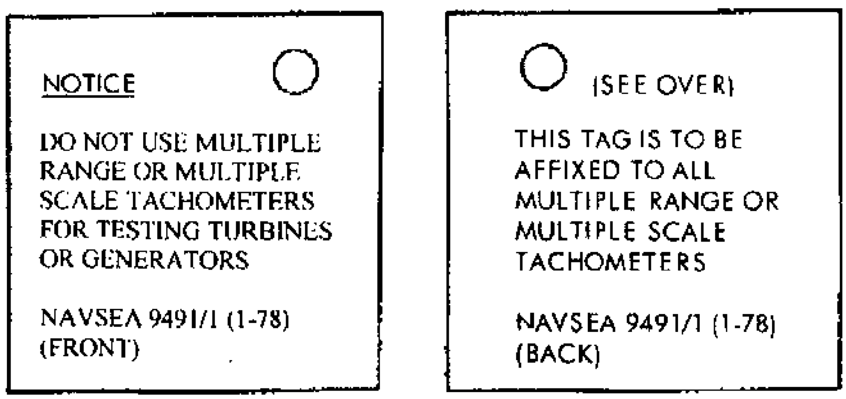



Figure 504-11-1. Tag for Multiple Range and Multiple Scale Tachometers

504-11.3.3 STROBOTACH OPERATION. When using both an optical tachometer and a strobotach for speed measuring, a problem that may occur is light interference. Strobe flashes may interfere with the optical tachometer, resulting in unrealistic indications of speed. When using both a strobotach and an optical tachometer, care should be taken in directing the strobe flashes so that they do not interfere with the optical tachometer. This may be accomplished by making the speed measurements at opposite ends of the shaft or by separating the two measuring instruments as far apart as is practical.

## 504-11.4 DESCRIPTION/OPERATION

504-11.4.1 PORTABLE (HANDHELD) TACHOMETERS

504-11.4.1.1 Chronometric. With the chronometric tachometer, the rotary speed of any accessible shaft is obtained by taking the average speed over a short time period. The instrument is a combination timepiece and mechanical revolution counter with a simultaneous start/stop mechanism. Rotary motion is converted into angular displacement reading on a dial scale in r/min. The specified range of the chronometric tachometer is 0 to 10,000 r/min with an allowable error of not more than 10 r/min for scale readings from 500 to 1000 r/min, and 0.5 percent of full scale for readings from 1000 r/min to the maximum scale reading.

504-11.4.1.1.1 To take a reading, place the spindle tip of the tachometer accurately on the center of the shaft. Press the starting button or lever. Then release the button. In about 5 seconds the instrument will automatically shut off and register r/min based on the average speed during its operating time. The reading is retained on the dial until the point is returned to zero by a reset button (usually the same as the starting button). Each portable chronometric tachometer, like the centrifugal tachometer discussed in paragraph 504-11.4.1.2 is supplied with a number of drive tips. Portable tachometers of the chronometric or centrifugal type are used for intermittent readings only and are not used for continuous operation.

504-11.4.1.2 Centrifugal. The portable centrifugal tachometer gives a continuous indication of rotary speed. Like the chronometric type, it is used on any accessible shaft. The instrument, read in r/min, converts rotary motion into angular displacement with a flyball governor linked to an indicating pointer. It is made with ranges between 50 and 50,000 r/min with an allowable error not more than 1.0 percent of full scale reading. Figure 504-11-2 and Figure 504-11-3 illustrate single range portable centrifugal tachometers. To take a reading, place the spindle tip of the tachometer accurately in the center of the shaft. Hold it in line with the shaft for a short time to note the reading. The centrifugal type registers r/min automatically as long as it is in contact with the shaft. Measurement of r/min permits a visual indication of the variation in speed. A means is provided for retaining the reading after the spindle is disengaged. The reading is the r/min at the instant of disengagement.

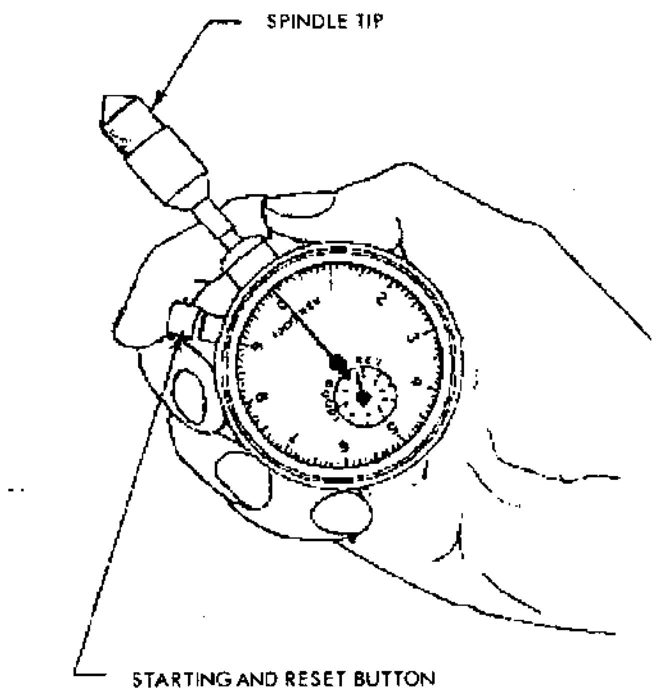



Figure 504-11-2. The Portable Chronometric Tachometer

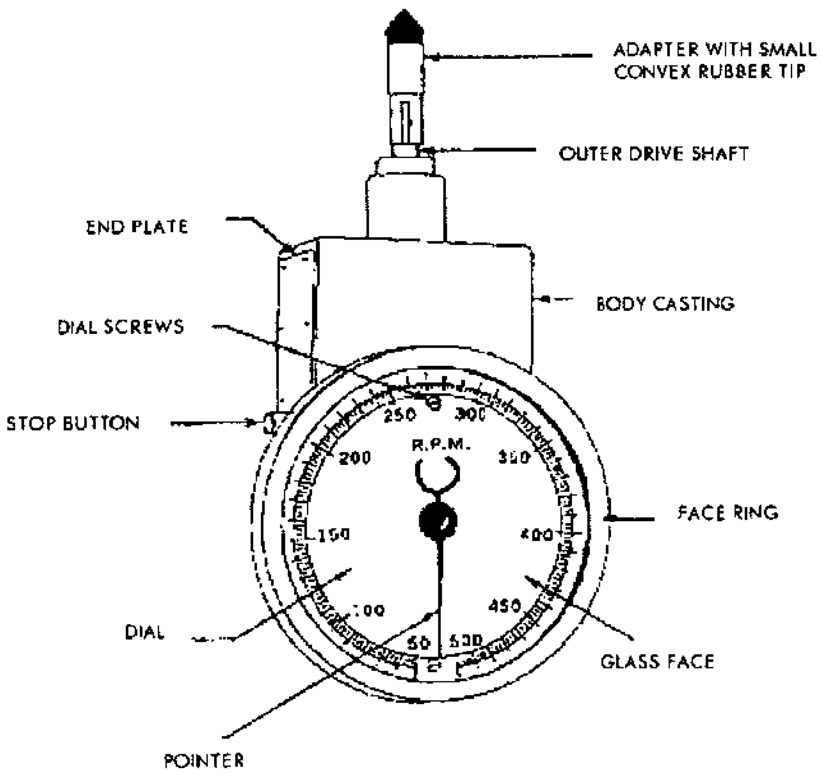



Figure 504-11-3. Single Range Centrifugal Tachometer

504-11.4.1.3 Rosonant (Vibrating Reed). The vibrating reed tachometer is used to measure r/min in cases where the rotating shaft is not readily accessible or where the extra load of a rotating tachometer would modify the shaft speed. This tachometer (see Figure 504-11-4) operates by contact with the machine under test. The free ends of accurately tuned reeds are observed against a scale calibrated in r/min. Speed is indicated by the reed tuned nearest to the vibrational frequency of the machine. This reed vibrates at a maximum amplitude. The instrument has a relatively narrow speed range per single unit, the widest being a ratio of maximum to minimum speed of about 4 to 1. However, many ranges of single units are available; as a group, they cover an overall range of speeds from 900 to 100,000 r/min. Accuracy depends on the interval between reeds and the ability of the operator to interpolate in these intervals.

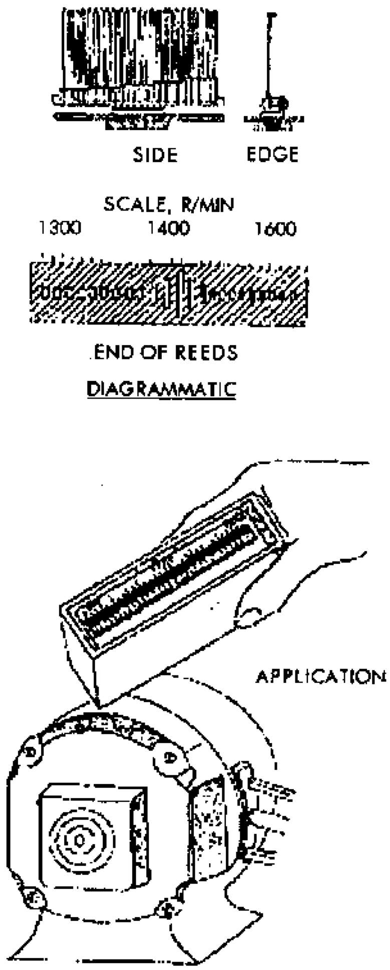



Figure 504-11-4. The Vibrating Reed Tachometer

504-11.4.2 DESCRIPTION/OPERATION OF ELECTRICAL TACHOMETERS

504-11.4.2.1 Stroboscopic Tachometer. For information on stroboscopic tachometers refer to **NSTM Chapter 491, Electrical Measuring and Test Instruments** .

504-11.4.2.2 Photo-Electric Tachometer. The photo-electric tachometer is a battery operated, computer-circuitry-controlled non-contact type tachometer used for continuous indication of rotary speed. The instrument contains a visible light source optically aligned with a light detector. It detects rotary speed by directing the visible light beam to a piece of self-adhesive reflective tape provided at a convenient point on the rotating component. The optical sensor detects the presence of the reflective tape as it passes through the light beam and a micro computer within the instrument quickly indicates the number of r/min on the LED display. The specified range of the photo-electric tachometer is 6 to 30,000 rpm with an allowable error of ± 1 rpm from 6 to 5000 rpm and ± 2 rpm from 5000 to 30,000 rpm.

504-11.4.2.2.1 To take a reading, clean shaft of grease and oil and place a small piece of reflective tape on the surface of the shaft. Direct the instrument perpendicular to the shaft at a distance of between 2 inches to 2 feet. Press and hold the on-off switch. A dot will appear on the display when the unit is properly aligned. Hold the on-off switch on. The display will update at approximately 1 second intervals. The on-off switch must be released prior to removal of the tachometer from the rotating object. After release of the power switch, the last reading will be displayed for a period of 10 seconds. Readings will be automatically stored in the memory for 4 minutes following release of the memory or power switch. This 4 minute retention may be extended any number of additional 4-minute periods by re-pressing the memory switch.

504-11.4.3 ACCESSORIES

504-11.4.3.1 General. Except for the resonant and photo-electric type, portable tachometers are usually provided with various friction tips and extensions, such as:

a. Triangular steel tip (may be the drive spindle itself)

b. Conical rubber tip, metal mounted (convex)

c. Rubber-lined metal cone tip (concave)

d. Rubber-tired wheel tip of known circumference (useful where the end of the shaft is inaccessible or when measuring linear velocity)

e. Extension rod (about 4 inches long)

504-11.4.3.2 Reflective Components. The photo-electric tachometers are usually provided with reflective tab sheet containing (1/2″ X 1/2″) pieces of reflective tape for most applications. The non-reflective area must always be greater than the reflective area. For locations consisting of both a dark environment and a dark shaft surface, components such as white paint or white chalk can be used as an adequate target for the photo-electric type.

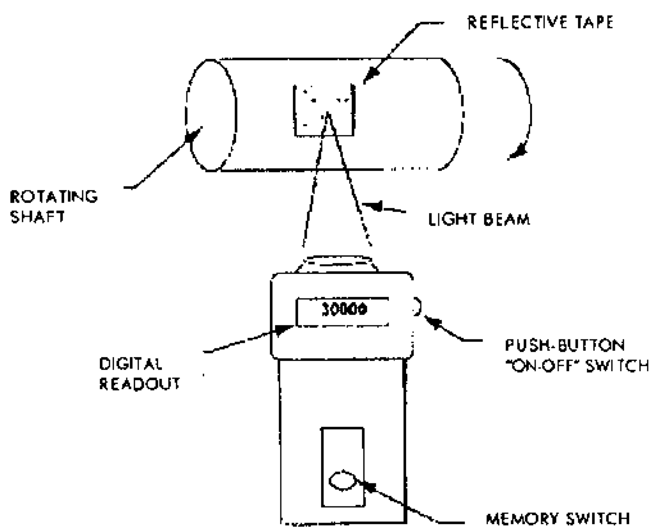



Figure 504-11-5. The Photo-Electric Tachometer

**504-11.5 FIXED (CONTINUOUS DURY) TACHOMETERS**

504-11.5.1 MAGNETO GENERATOR-VOLTMETER TYPE. This type of tachometer consists of a generator which is driven by direct coupling or external gearing from the shaft being measured, and a dc voltmeter which is designed for panel mounting. The generator develops a dc voltage signal which is directly proportional to the speed at which it is driven. This signal is then transmitted to a permanent magnet-moving coil voltmeter calibrated in r/min. Direct coupling limits the top measured speed to 2500 r/min, whereas 25,000 r/min is attainable with suitable reduction gear drive. The allowable error for this system is no greater than 2.0 percent of full scale reading.

504-11.5.2 ALTERNATING CURRENT VOLTAGE RESPONSIVE TYPE. The ac voltage responsive type fixed tachometer consists of a permanent magnet type ac generator, a suitable rectifier-control, and an indicator of the voltmeter type. The system is usable where speeds range from 500 to 5000 r/min. The allowable error is no greater than 2.5 percent of full scale reading.

504-11.5.3 FREQUENCY RESPONSIVE TYPE. The frequency responsive tachometer consists of a permanent magnet type ac generator, a control network box, and an indicator of the dc permanent-magnet, moving-coil type with current sensitivity and resistance, to provide continuous instantaneous indications of shaft speed. The generator consists of a permanent-magnet rotor which is mounted to the end of the rotating shaft and a stator which is mounted to or incorporated in the stationary frame of the machinery. The number of poles of the rotor and stator, and the size of the rotor may be varied to suit the specific speed requirements. The method of mounting or adapting the stator may be varied to suit the machinery details. In operation, rotation of the rotor within the stator generates ac voltage. The frequency of this voltage is directly proportional to the speed of the generator. This variable frequency voltage is fed to the control box which transforms the output into a dc current proportional to the speed of the shaft being measured. The tachometer is designed for installations where speeds from 500 to 100,000 r/min exist. Allowable error is no greater than 2 percent of full scale reading.

504-11.5.4 FREQUENCY SENSITIVE TYPE. The frequency sensitive tachometer consists of a magnetic reluctance pickup, a frequency sensitive transducer, and a rotary speed-indicating device. The pickup consists of a coil, pole piece, magnet and housing and is referred to as a variable reluctance sensor (VRS). The end face of the pole piece is placed close to the rotating shaft being measured. As a ferrous object approaches the tip of the pole piece, the magnetic field increases inducing a voltage in the coil in one direction. As the object moves away from the pole piece the magnetic field decreases inducing a voltage in the coil in the opposite direction. The passage of one ferrous object (such as one gear tooth) induces one cycle of ac voltage. Therefore the ac voltage is proportional to the rate of change of magnetic flux and is generally proportional to speed. The frequency of the ac signal is exactly proportional to the speed or RPM (i.e., the passing of 500 gear teeth in one second produce a frequency signal of 500 Hz). The transducer converts the voltage pulses from the magnetic pickup into an output proportional to the speed of the shaft. This signal is then fed to the applicable RPM indicator.

504-11.5.4.1 Target Considerations. The most commonly used actuator is a metal gear, but other appropriate targets are bolt heads, keys, keyways, magnets, holes in a metal disc, and turbine blades. In all cases, the target material must be a ferrous metal, preferably unhardened.

504-11.5.4.2 Pickup Selection/Application Considerations. A number of types of magnetic pickups exist due to considerations such as temperature, environment, mechanical size, and pole piece configurations. However, the main selection should be based on the surface speed of the object, the gap between the pole piece and the target, the target size (or discontinuity) and the load impedance connected to the pickup. For system applications requiring sensing extremely low speeds or for systems requiring square wave logic output (TTL) an active pickup should be considered. These sensors provide, via a pulse train output, a valid speed indication of a rotating target having a metal discontinuity. Active pickups utilize several technologies, but in general they have the following characteristics: require dc power for operation, provide a constant amplitude square wave output, and have a very good low speed response (to ″zero speed″ for some types).

504-11.5.5 OIL PRESSURE OPERATED. On boiler forced-draft blowers, the lubricating oil pump runs at a speed directly related to the blower speed so the oil pressure corresponds to a given number of r/min of the blower. The oil pressure is read with a common pressure gage graduated in r/min and lb/in2. The pressure graduations are used only for calibrating the gage. The oil pressure gage is used for direct indication, whereas an oil-air pressure transmitter is used to supply an actuating air signal to a remote pneumatically-operated speed indicator.

504-11.5.6 TACHOMETER CONFIGURATIONS IN CONTROL SYSTEMS. A number of shipboard systems such as power turbines, gas turbine generators, or main reduction gear use the frequency signal from a magnetic pickup or tachometer generator to control relays, speed control and remote indications. These signals are then transmitted to a signal conditioner card within the signal conditioning enclosure or free standing electronic enclosure from which it is conditioned and sent to a control system. The control system then monitors the speed of the power turbine, turbine generator or shaft speed and provides functions such as generation of alarm signals, generation of system shutdown signals when speeds are in excess or drop below desired setpoints, and limitation of the turbine speed when speed setpoints are exceeded. The speed indication is read directly from the demand display indicator and digital meters of the associated control console and on panel meters at the propulsion auxiliary and propulsion local control consoles.

504-11.5.7 OVERSPEED PROTECTION SYSTEMS. Systems such as main feed pumps incorporate a separate safety shut down system for protection from turbine overspeed. The system consists of a main control overspeed trip unit, a remote indicating unit, an alarm panel and a magnetic pickup. The magnetic pickup provides the main control unit with a signal proportional to pump speed. The main control unit will monitor and display main feed pump speed, activate a trip valve in the event of main feed pump overspeed, and provide various local and remote, visible and/or audible alarms. The trip valve will activate upon command of the main control unit to secure steam to the turbine. The remote indicating unit provides a visual indication of the steam turbine operating condition at a remote location such as an enclosed operating station.

504-11.5.8 OVERSPEED PROTECTION SYSTEMS. These systems provide a means of determining and indicating revolutions per minute, direction of rotation, and total revolutions of the propeller shafts. They incorporate a number of different sensing techniques including the use of a variable reluctance pickup to obtain shaft speed indications. For information on the propeller revolution indicators refer to Section 12, Propeller Revolution Counters.

## 504-11.6 FUTURE TECHNOLOGY

504-11.6.1 GENERAL OVERVIEW. For future applications, fiber optic sensor technology is being considered as a means for measuring rotational speed. The integration of this technology into the fleet would result in the ability to monitor and process more information from a number of different ship systems at higher data transfer rates than the conventional sensors. Additionally, using fiber optic technology would allow multiplex sensing capability of a system’s speed output with a variety of other sensor parameters such as pressure, temperature, liquid level, etc., contributing to cost reduction.

504-11.6.2 SENSOR TECHNIQUES. Manufacturers currently utilize three techniques of applying fiber optic technology for the measurement of rotational speed: reflection, beam interruption, and magneto-optic (Faraday) effect.

504-11.6.2.1 Reflection. In the reflection design the fiber optic tachometer provides a readout of rate-of-rotation by converting the frequency of the reflection of a light beam, from the reflective target on the rotating part, to a digital signal that indicates RPM. The unit consists of a sensor head, an optical fiber, and an opto-electronics unit. The sensor head, which does not contain any electrical components, is placed in close proximity to the rotating shaft being measured. In operation, light from an LED within the opto-electronics unit is injected into the optical fiber to the sensor head. When the reflective target is opposite the sensor, the light is reflected back into the fiber and transmitted to the opto-electronics unit. In the opto-electronics unit a photo-detector converts the light or optical source to an electrical signal, which is processed and displayed as a rotational rate. The frequency of the reflected signal is a direct indication of the shaft speed.

504-11.6.2.2 Beam Interruption. Using the beam interruption principle the fiber optic tachometer provides a readout of shaft speed by converting the frequency of interruption of a light beam, due to a slotted target or a series of blades, to a digital signal that indicates RPM. The unit consists of two sensor heads, two optical fibers, and an opto-electronics unit. Light is sent from an LED within the opto-electronics unit down a fiber to a sensor head, where the light exits the transmitter fiber and crosses a gap. A second sensor head is used to collect the light and focus it into the receiving fiber. A slotted target, blades of a fan, etc. are attached to the rotating shaft. The ″teeth″ of the slotted target or fan blades pass through the gap between the fibers and block the light every time a tooth is rotated into position. Thus the passage of a tooth is indicated by an interruption of the light signal. The frequency is a direct indication of shaft speed.

504-11.6.2.3 Magneto-Optic (Faraday) Effect. Using the Magneto-Optic (Faraday) effect for measuring speed, light is transmitted through a fiber to and from the sensor while the rotating shaft modulates the magnetic field within the sensor. The unit consists of a sensor head, an optical fiber, and an opto-electronics unit. The sensor head is placed in close proximity to a ferrous target on the rotating shaft. This target may consist of a bolt pattern, gear teeth, etc. In operation, light is transmitted from the opto-electronics unit through the optical fiber and into the sensor head. In the absence of a magnetic field, the light passes through unaffected. However, when a ferrous target passes by the sensor head the magnetic field within the sensor is altered resulting in a change in the light intensity. The signal which is intensity modulated with the frequency of gear tooth passage is then captured and transmitted through an optical fiber to the opto-electronics unit. This signal is then converted to a shaft speed indication.

## 504-11.7 CARE OF TACHOMETERS

504-11.7.1 HANDLING AND ENVIRONMENT. Tachometers are delicate instruments and should be handled with care to prevent unnecessary shocks and jars. Avoid sudden applications of load. Use care in aligning the tachometer with the rotating shaft. With portable instruments, align the spindle as nearly as possible with the axis of the shaft. Avoid installation in unfavorable environments such as excessive humidity, acid, or fumes. Except for the vibrating reed type, portable tachometers are designed only for intermittent readings and should never be used for continuous service. Portable tachometers, when not in use, should always be kept in the case provided and stowed in a dry place comparatively free from vibration and jars. It is important that all recommendations of the manufacturer be carefully followed in the use of any instrument.

504-11.7.2 MAINTENANCE AND LUBRICATION. In general, preventive maintenance includes keeping the instruments clean, free running, and properly lubricated. Lubricate according to the manufacturer’s recommendations when technical manuals are available. Otherwise lubricate in accordance with these rules:

1. Lubricate only through oil holes or oil cups provided.

2. Use a light viscosity watch or clock oil, free of impurities.
3. Use no more than one small drop in each bearing.
4. Never oil the governor spindle of centrifugal tachometers.
5. Oil at regular intervals of running time.

504-11.7.2.1 Magneto Generator-Voltmeter Type. The grease-sealed bearings of the magneto units should require no lubrication. If faulty indicator readings are observed, the magneto cover should be removed and the commutator and brushes inspected for mechanical condition, cleanliness and proper contact. If dirty, the commutator may be cleaned by holding a clean lint-free cloth against the commutator while the magneto is running. If the brushes are rough or badly worn they should be replaced with a new set, which includes directions for proper installation.

504-11.7.3 REPAIR. The NAVSEA or manufacturer's technical manual should be used as an informational source for trouble diagnosis, parts identification, and repair data.

504-11.7.3.1 Replacement/Troubleshoot Precautions for Fixed Tachometers.

504-11.7.3.1.1 Rotor Replacement for Frequency Responsive Type. When replacement of the tachometer generator (comprised of the rotor and stator) is required the rotor and stator are provided separately. To maintain the magnetic flux in the charged rotor, a keeper is supplied. The keeper is a cylindrical piece of steel which fits around the rotor and should be kept in position until the rotor is mounted in the stator. The keeper should be kept on the rotor whenever the rotor is not in the stator, or removed from the shaft. Generally, the rotor is mounted on the shaft and the stator on a fixed support. If at any time the stator is removed from around the rotor, the keeper should be mounted on the rotor to retain the magnetic properties of the rotor and thereby maintain the accuracy of the original system calibration. If the original keeper is misplaced or otherwise unavailable, any piece of magnetic metal which is somewhat pliable will perform the same function.

504-11.7.3.1.2 Connections to Magneto Generator-Voltmeter Type. In the installation and servicing of the magneto generators, care should be taken not to accidentally connect any external power source to its windings since even the momentary application of more than three volts may seriously damage the magneto and/or associated meters. In the installation and servicing of the indicator, extreme care should be taken not to accidentally connect any external power source to the meter terminals, since even a momentary application of more than three volts may cause serious damage to the meter.

## 504-11.8 CALIBRATION

504-11.8.1 METHOD. When high accuracy in the measurement of rotary speed is required, the tachometer must be calibrated and the proper corrections made. One way to calibrate a direct-reading tachometer is to drive the tachometer with a motor capable of being run at a very constant and controllable speed, measured by a very constant and controllable speed, measured by a positively driven standard instrument. The standard instrument may be an electronic tachometer with a calibrated crystal-controlled synchronized time base or a mechanical counter with an accurate, synchronized time base. An unsynchronized counter and timepiece (stopwatch) can be used if the speed control is sufficiently good to permit a time interval long enough to make the start and stop error, negligible, usually about 2 minutes. For on site calibrations, one method of verification of the speed of a system such as a power turbine is with the use of a frequency synthesizer, digital multimeter, and isolation transformers. The magnetic pickup is disconnected and a frequency synthesizer and isolation transformer are connected in its place. The frequency synthesizer is then set to various frequency values and the associated speed indications, overspeed trip alarms and logic states are verified at the corresponding electronic control console and local operating panel meters.

504-11.8.1.1 In the special case of oil pressure tachometers, calibration is accomplished by use of standard pressure calibrating equipment such as a master gage or a deadweight tester. Since the relation between r/min and lb/in2 is constant and the gage dial contains both scales, a calibration of pressure will result in the gage indicating speed correctly.

504-11.8.2 PERIODICITY. Calibration intervals are assigned in accordance with NAVSEA's Metrology and Calibration Program and the Field Calibration Activity Metrology Requirements List, based on the criticality of the tachometer system. Common calibration intervals are twelve and eighteen months.

# SECTION 12.

# PROPELLER REVOLUTION INDICATORS

## 504-12.1 ENGINEERING PRINCIPLES

504-12.1.1 GENERAL DESCRIPTION. The propeller revolution indicator system is a system which provides a means of determining and indicating revolutions per minute, direction of rotation, and total revolutions of the propeller shafts. Ship's force personnel will utilize the total revolution data plus the rpm and direction of shaft rotation data for the ship's operational purposes. Use of rpm and direction of shaft rotation information from the digital indicator on the bridge or at navigation or control console verifies the ship's operational status and actions taken in response to commands from other systems, such as engine order or propeller order.

## 504-12.2 DEFINITION

504-12.2.1 SYNCHRONOUS REFERENCE SPEED. Synchronous reference speed is the speed provided by a synchronous motor within the indicator-transmitter unit used for comparison to the variable speed input received from the transmitter.

504-12.2.2 CRYSTAL OSCILLATOR. An oscillator whose output frequency is controlled by a piezo-electric crystal, usually for the purpose of improved frequency stability and accuracy.

504-12.2.3 EXCITATION. Excitation is the disturbed or altered condition resulting from stimulation of an individual power source.

## 504-12.3 SAFETY

504-12.3.1 GENERAL PRECAUTIONS. Connecting gears of propeller revolution indicators must be covered for protection of both personnel and gears. Rotating pins and projections liable to catch clothing should be eliminated or covered.

## 504-12.4 DESCRIPTION

### 504-12.4.1 SYNCHRO TYPE

504-12.4.1.1 System Components. The synchro system is typically comprised of transmitters, indicator-transmitters, and remote indicators. In operation, the physically driven transmitter, one for each propeller shaft, transmits to its associated indicator-transmitter, which indicates propeller speed, direction and totalized revolution count. The indicator-transmitter, in turn, transmits to one or more indicators, which merely repeat the desired data at other remote locations, as required.

504-12.4.1.1.1 Transmitter. The transmitter is either gear-driven from the propeller shaft or is direct-coupled to the end of a stub shaft of the propulsion machinery, as the particular installation requires. The major functioning parts of the unit are the synchro generator, revolution totalizing counter and the indicator signal-energizing contact assembly all of which are actuated by suitable gearing. The entire mechanism is mounted in a watertight aluminum housing.

504-12.4.1.1.2 Indicator-transmitter. The indicator-transmitter is designed for panel mounting and performs the functions of both speed indication and transmission, in addition to providing rotational direction information and a totalized count of propeller revolutions. The major operating parts of the instrument are the receiving synchro motor, transmitting synchro generator, constant speed and follow up motors, revolution counter, backing signal, dial and pointers all of which are mounted in an aluminum housing.

504-12.4.1.1.3 Indicator-transmitter. The indicator-transmitter is designed for panel mounting and performs the functions of both speed indication and transmission, in addition to providing rotational direction information and a totalized count of propeller revolutions. The major operating parts of the instrument are the receiving synchro motor, transmitting synchro generator, constant speed and follow up motors, revolution counter, backing signal, dial and pointers all of which are mounted in an aluminum housing.

### 504-12.4.2 VARIABLE RELUCTANCE TYPE

504-12.4.2.1 System Components. The variable reluctance system is typically comprised of transmitters, indicator-transmitters, and remote digital indicators. In operation, the transmitter has a mechanical input from the propeller shaft and produces two electrical outputs that are the RPM pulse output and the revolutions pulse output. The unit also provides a contact closure corresponding to the direction of propeller shaft rotation and registers the total number of revolutions of the propeller shaft input. The indicator-transmitter receives the RPM pulse and the revolution pulse from the transmitter and provides an indication of the total number of revolutions of the propeller shaft and an analog propeller RPM that is proportional to the input frequency and the propeller RPM. The indicators receive the pulse output signal from the transmitter and convert this to a digital RPM readout. Further details on the system components are described in paragraphs 504-12.4.2.1.1 through 504-12.4.2.1.3. Figure 504–12–1 illustrates a typical configuration of the variable reluctance type revolution counter transmitter mounted in conjunction with a tachometer signal generator on the ship's reduction gear assembly.

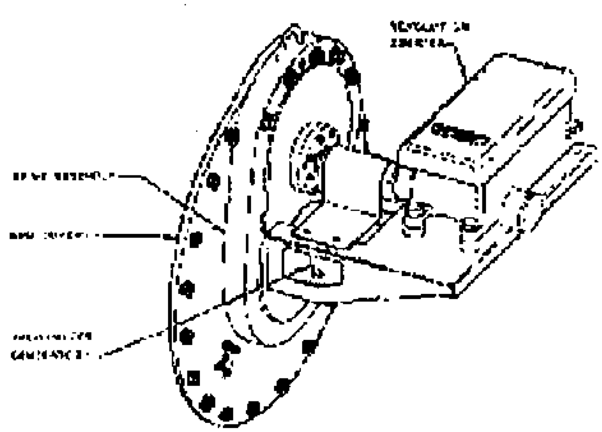


Figure 504-12-1. Variable Reluctance Type Revolution Counter Transmitter

504-12.4.2.1.1 Transmitter. The transmitter is either gear-driven from the propeller shaft or is direct-coupled to the end of a stub shaft of the propulsion machinery, as the particular installation requires. The major functioning parts of the unit are the RPM and revolution reluctance pickups, a revolution totalizing counter and a switch which is mechanically actuated to close a contact corresponding to the direction of propeller shaft rotation. These components are all contained within an watertight aluminum housing.

504-12.4.2.1.2 Indicator-Transmitter. The indicator-transmitter is designed for panel or bulkhead mounting in the engine room or other location selected and provides an analog presentation of rpm and a digital presentation of revolutions. The unit also provides an output signal for remote speed indication. The major operating parts of the instrument are a power supply and driver, frequency to dc converter, revolution counter, backing signal, and analog meter for propeller rpm indication.

504-12.4.2.1.3 Indicator. The digital indicator receives the RPM pulses from the transmitter and develops and indicates the RPM of the propeller shaft on a light emitting diode. The major operating parts of the instrument are the digital tachometer and backing signal light housed in an aluminum enclosure for panel or bulkhead mounting.

504-12.4.3 MAGNETO TYPE

504-12.4.3.1 General. In certain applications, a magneto system typically comprised of a revolution counter and elapsed time indicator is used to maintain a visual record of propeller revolutions and hours of operation. In operation, the counter and elapsed time indicator are mechanically driven by the pinion gear train of the main propulsion speed decreaser gears. These gears transmit the power developed by the main propulsion gas turbines to the propeller shafts. The magneto within the unit generates an electrical signal in order to run the unit's associated counter and timer. The revolution count and elapsed time figures are read directly on the face of the instrument. The magneto type revolution counter and elapsed time indicator are shown in Figure 504–12–2.

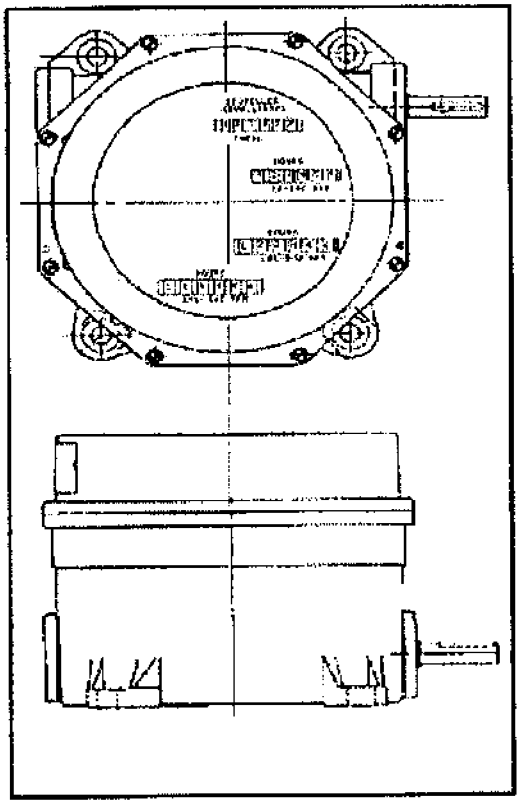


Figure 504-12-2. Magneto Type Revolution Counter

504-12.4.3.2 Integral Revolution Counter. Other shipboard applications involve a revolution counter, which is a component of the tachometer drive assembly of the ship's main propulsion reduction gear assembly. The counter is linked to the shaft of the tachometer drive assembly through a belt and pulley configuration. The counter's function is to simply display the continuous totalized shaft revolutions.

## 504-12.5 TYPE DESIGNATIONS

504-12.5.1 The transmitter units are available in several different types. The differences are in their internal ratios and the machining on the ends of their drive shafts. The speed ratio between the propeller shaft and the transmitter shaft and the method of driving the transmitter from the propeller shaft or propulsion equipment is reflected in the type designation. For example, in the case of an IC/3A, the ″3″ denotes the transmitter shaft must be driven at three times the propeller speed and the ″A″ indicates that the shaft end is keyed and threaded for spur gear drive. The indicator-transmitters and indicators are also available in several different type designations. These designations reflect features such as dial size, mounting, dial illumination, revolution counter, speed range and special features. The symbols for the various type designations for the indicator-transmitter and the synchro transmitter units are outlined in the propeller revolution indicating equipment military specifications.

## 504-12.6 OPERATION

### 504-12.6.1 SYNCHRO TYPE

504-12.6.1.1 Transmitter. The transmitter units are physically driven at a rate proportional to propeller speed. By means of internal gearing and a uni-directional drive mechanism, the mechanical counter and synchro generator contained within the transmitter housing are both driven in a constant direction whenever the propeller shaft is turning in either rotation. The rotational output of the synchro generator is electrically transmitted to the remote indicator-transmitter and associated repeater indicators. The transmitter unit also closes electric contacts for operating reverse direction signals in the associated indicators when the propeller shaft rotates in the astern direction. The revolution counter is driven through helical gears at exactly one-tenth the propeller speed. Each revolution of the counter shaft registers a count of ten, therefore the counter is driven at one-tenth propeller speed.

504-12.6.1.2 Indicator-Transmitter. The indicator-transmitter units relate the variable speed input received from the transmitter to a fixed synchronous reference speed. It is driven electrically by its associated transmitter at a speed proportional to that of the propeller. The receiving synchro within the indicator-transmitter runs at exactly one-half the propeller speed and controls a mechanism which converts running speed into proportional angular positioning of the unit’s transmitting synchro and indicating pointers. The relative direction of the speed is indicated by a backing signal indicator which lights in the astern direction only. The angular rotor position of the synchro generator is electrically transmitted to receiving synchros in the remote indicators of ship systems as applicable. The indicator-transmitter also incorporates a revolution counter which is driven by the receiving synchro through gears at exactly one-tenth propeller speed. The counter registers ten counts per revolution of its shaft enabling propeller revolutions to be totalized directly in both the ahead and astern directions of rotation.

504-12.6.1.3 Indicator. The indicator contains a synchro motor and a pointer to indicate rotor position in terms of RPM. The synchro rotor is in angular correspondence with the indicator-transmitter’s synchro generator by means of electrical interconnection. Each indicator is provided with a red signal lamp which lights automatically whenever propeller revolutions are in the astern direction. The lamps are energized by switch contacts located in the associated shaft transmitter. Some indicators also contain a six figure revolution counter. This counter is driven by the unit’s synchro motor that is electrically connected to a synchro generator located in the shaft transmitter.

### 504-12.6.2 VARIABLE RELUCTANCE TYPE

504-12.6.2.1 Transmitter. An RPM or pulse signal is developed in the RPM reluctance pickup by the varying magnetic gap caused by rotation of gear teeth thus producing an output which is compatible with TTL logic. This signal is then fed to a digital indicator(s) for RPM digital readout. Additionally, a second reluctance pickup within the transmitter produces a pulse signal reflecting total shaft revolutions. This signal is transmitted to the indicator-transmitter unit for display. The transmitter also contains a switch which is mechanically actuated to close a contact corresponding to the direction of propeller shaft rotation. In addition, a mechanical six figure counter contained within the unit registers the total number of propeller shaft revolutions through internal gearing of proper ratio. The counter adds one count for ten propeller revolutions.

504-12.6.2.2 Indicator-Transmitter. The indicator-transmitter unit receives the RPM pulse from the transmitter and converts this pulse, by means of a frequency to dc converter, to a dc voltage that is proportional to RPM. This voltage is then supplied to the unit’s voltmeter which is calibrated in RPM and to a remote signal converter whose output is used to position remote indicators. The indicator-transmitter also receives the revolution pulse from the transmitter and by means of a driver, converts this signal to an appropriate form that can be used to energize a step motor. This step motor in turn drives a mechanical counter that displays the total number of revolutions of the propeller shaft. The unit’s power supply furnishes the dc power for the remote signal converter and the power for the driver.

504-12.6.2.3 Indicator. The indicator counts the number of RPM pulses during an accurate one second time interval that is derived from a crystal oscillator. Since the pulse frequency is arranged to equal RPM, the count in one second is a direct RPM reading. The information is updated at the same rate as the display time. This display time can be adjusted from approximately two to five seconds by turning the potentiometer on the front panel of the digital indicator.

504-12.6.3 MAGNETO TYPE

504-12.6.3.1 Transmitter. The transmitter for the magneto type is classified as a counter and elapsed time indicator. This unit is physically coupled to the driving stub shaft of the gear train of the main propulsion speed decreaser gears. By means of internal gearing the mechanical revolutions counter is driven in a constant direction whenever the propeller shaft is turning in either direction. This mechanical six figure counter registers the total number of propeller shaft revolutions. The counter adds one count for every ten propeller revolutions. A magneto within the unit, driven through internal gearing, generates an output voltage proportional to a given speed increment. This voltage is used to feed sensors which are adjusted to operate at given propeller RPM setpoints. These sensors are then used to activate relays whose contacts furnish electrical power to low timing motors which run the unit's elapsed time indicators. These indicators totalize hours of operation in three separate speed ranges 10-100 RPM, 101-140 RPM, and 141-180 RPM.

504-12.6.4 ACCURACY. The revolution totalizing counter within the propeller revolution system components is extremely accurate. These counters are driven in one direction only regardless of the direction of rotation of the propeller shaft by a unidirectional device. In operation of the unidirectional device, not more than 1/4 of a revolution in the counter shall be lost. The accuracy requirements for the synchro type system are listed in paragraphs 504-12.6.4.1 through 504-12.6.4.2.

504-12.6.4.1 Indicator-Transmitter. From 5 rpm to 1/10 of full scale reading, error shall be within ± 1/2 of 1 percent of full scale reading. From 1/10 of full scale reading to full scale reading, error shall be within ± 1/4 of 1 percent of full scale reading.

504-12.6.4.2 Indicators. For single pointer indicators error shall not exceed a tolerance of ± 1/2 of 1 percent of full scale reading. For multiple pointer indicators error shall not exceed a tolerance of ± 3/4 of 1 percent of full scale reading.

## 504-12.7 CARE AND MAINTENANCE

504-12.7.1 GENERAL. Preventive maintenance consists of keeping the equipment clean, free running and properly lubricated. During long periods of inactivity, the system should be deenergized. This will cause lower internal instrument temperatures reducing the gravitational tendency of hot lubricants to drip out of the mechanism when not in motion.

504-12.7.1.1 Transmitters. For the transmitter units, the condition of the gear teeth should be examined and accumulated dirt or hardened lubricant should be removed. Lubrication of the teeth of all running gears including the unit's worm and worm gear should be conducted following the guidelines in the applicable technical manual. For the synchro units, the transmitter's synchro generator should be removed from its base and examined for freedom or rotor movement.

504-12.7.1.2 Indicator-Transmitter. The internal components such as the worm gearing, synchronous motor (as applicable), and helical gears should be lubricated in accordance with the guidelines outlined in the applicable

Naval technical manual. Observe that the unit's slip-rings and electrical contacts be clean and free of any lubrication to ensure that faulty electrical contacts do not impair the action of the indicator-transmitter's follow up motor. After a prolonged period of operation, the electrical contacts should be cleaned by drawing an alcohol soaked piece of paper between the manually closed set of contacts. The use of sandpaper or emery cloth is not recommended, but a jeweler's file may be used if the alcohol and paper method is inadequate.

504-12.7.1.3 Indicator. Inspection of the indicator units involves verification that none of the lamps in the unit have burned out. For the synchro indicators ensure the synchro rotor turns freely. Instructions for removing the indicator mechanisms from their respective housing are listed in the applicable Naval technical manual.

## 504-12.8 TROUBLESHOOTING

504-12.8.1 GENRAL GUIDELINES. Corrective maintenance usually follows faulty operation observed at the indicator-transmitter and/or one or more of the repeater indicators. The technical manuals for this equipment contain specific information on troubleshooting and corrective action, however, some general troubleshooting guidelines for the system components are listed in paragraphs 504-12.8.1.1 through 504-12.8.1.2.

504-12.8.1.1 Transmitters. Removing the cover and rotating the main shaft should cause a corresponding rotation of all internal gearing, counter gear and synchro gear as applicable. A failure of gears to turn smoothly when driven by the shaft indicates slippage or disengagement is present in the gear train. Verification of all gearing for proper mesh and positive drive shall be made when the main shaft is turned in both rotations. Operation of the mechanical revolutions counter in the variable-reluctance transmitter ensures that there is mechanical input to both the RPM and revolution reluctance pickups. For the synchro unit, an ohmmeter can be used to check the synchro windings for continuity and resistance. Failures noted with the time counters of the magneto transmitters can be detected with the use of a voltmeter enabling isolation of a defective part such as a voltsensor, relay, timing motor or mechanical counter.

504-12.8.1.2 Indicator-Transmitter. Indicator-transmitter units in the synchro type contain three motors, and the failure of one or more to start or run properly is usually found to be the cause of unsatisfactory performance. Prior to concluding that the motor is defective however, verification of the presence of voltage should be made directly at the motor terminals to ensure that they are actually energized. Motors may be precluded from running by reason of mechanical sticking or binding of associated running parts such as gears, shafts or bearings. Gears and bearings should be inspected for dirt or other discrepancies. If the synchro motor fails to rotate when the circuit is energized and the associated propeller shaft is turning over, a check of the rotor and all associated shafting should be made for freedom of rotation. For the variable-reluctance type, a general observation of a speed indication at the voltmeter will verify the frequency to dc converter is operating. An observation of RPM indication at the digital indicator will verify that the RPM reluctance pickup and its dc power supply are operating.

## 504-12.9 INSTALLATION CONSIDERATIONS

504-12.9.1 GENERAL. In a newly installed synchro system, ensure that the synchro units are correctly zeroed and properly wired. Improper zeroing or incorrect connections are the major sources of trouble with new installations. Verification of the color coding of the wires should be made with an ohmmeter. Another major source of trouble in new installations is improper excitation. The entire system must be energized from the same power source for proper operation.

504-12.9.2 MECHANICAL ALIGNMENTS. Verify that the flexible coupling connecting the transmitter unit of the revolution indicator with the stub shaft of the propulsion machinery rotates with no evidence of binding or erratic operation. If there is binding or erratic operation follow the installation procedures cited in the applicable Naval technical manual. Additionally, the transmitter units should be rigidly mounted in a horizontal position, in such a manner that minimum radial and no axial loading is exerted on the unit's drive shaft.

### 504-12.10 CALIBRATION

504-12.10.1 The propeller revolution indicators are normally configured so that the propeller revolution transmitter unit is mounted in conjunction with a tachometer signal generator or magnetic pickup. These components are all supplied as part of the drive assembly of the main reduction gear. Calibrations are conducted by simulating the output of the tachometer generator or magnetic pickup (as applicable) with the use of a frequency synthesizer. The synthesizer is connected to the tachometer generator or pickup terminals and set to various frequencies corresponding with desired rpm indications. The speeds are then verified at the associated propulsion auxiliary, local control, and ship control consoles and the bridge digital display units.

504-12.10.2 Calibration intervals are assigned in accordance with NAVSEA's Metrology and Calibration Program and the Field Calibration Activity Metrology Requirements List, based on the criticality of the propeller revolution indicating system. Common calibration intervals are twelve and eighteen months.

## SECTION 13.

## FLOWMETERS

### 504-13.1 ENGINEERING PRINCIPLES

504-13.1.1 Numerous methods exist for measuring fluid movement in a closed system. Two basic categories of fluid monitoring will be described in this section. These categories are velocity (or rate of flow) measurement, and total flow measurement. Rate of flow is the amount of fluid that flows past a given point at any instant in time. Total flow is the amount of fluid that moves past a given position during a definite period of time. However, information from one type of meter may be used to infer other information. For example, accumulating rate of flow information over time provides total flow value, and the rate of total flow accumulation is interpreted as flow rate.

504-13.1.2 No one type of flowmeter has been found that will be applicable to all types of fluids, provide a high degree of accuracy over a large flow rate range, and will not be affected by changes in fluid type while not interfering with the system process. Flowmeters are placed into several categories based on a principle of operation. Each category of flowmeter is then reduced to smaller subcategories. This is required to accommodate the variation of fluid properties, flow rate ranges and system use requirements.

504-13.1.3 System requirements will ultimately dictate selection of a flowmeter. The accuracy requirement for the system is probably the most important consideration. Flowmeters which are required to be mounted in a piping system are among the most reliable. However, the cost of these flowmeters increases dramatically as pipe size increases. The system fluid may limit selection of a flowmeter type. For example, particulate material in the flow stream will cause most flowmeters to fail prematurely, but may be a normal byproduct of the monitored system's operation. While electrical power is required for some flowmeters, many provide a visual indication of flow without external power.

## 504-13.2 DEFINITIONS

504-13.2.1 FLOWMETER. A **flowmeter** is a device for measuring the quantity of a fluid moving through a pipe. The **primary device** of a flowmeter interacts with the fluid to generate a signal or reaction related to the movement of fluid. The **secondary device** of the flowmeter receives the signal from the primary device and displays or records the detected fluid movement. Observe the directional arrow markings on the flowmeter when installing. Flow through the flowmeter must always be in the indicated direction.

504-13.2.2 FLUID PROPERTIES. The physical properties of fluids important in measuring flow are pressure, composition, density, temperature, viscosity, and compressibility.

504-13.2.2.1 Pressure is defined as force per unit area. Pressure can be referenced to atmospheric conditions (gage pressure) or be comprised of atmospheric and gage pressure (absolute pressure).

504-13.2.2.2 Composition refers to the purity of the fluid. If the fluid is a single component, the fluid is said to be homogeneous. If the fluid contains two or more components the fluid is considered heterogeneous.

504-13.2.2.3 Density is mass per unit volume. It is usually expressed in lbm/volume (lbm is pounds mass).

504-13.2.2.4 Viscosity describes a fluid's resistance to flow (shear stress). The units of absolute viscosity are actually mass per foot-seconds, also known as centipoise. Absolute viscosity divided by fluid density is known as kinematic viscosity. Kinematic viscosity is generally referred to in units of centistokes. Viscosity can also be expressed in the units by which it is measured with a viscometer, such as Saybolt Universal - Saybolt Seconds Universal (SSU). In most tables, viscosity is expressed in metric units: centipoise for absolute and centistokes for kinematic viscosity respectively. These may be converted using the following relationships:

Lbm/ft-sec = 14.8816 poise = 1488.16 centipoise (absolute viscosity)

$ft^2$ /sec = 929.03 stokes = 92903 centistokes (kinematic viscosity)

504-13.2.2.5 Fluid compressibility refers to change in fluid density over time. If a fluid is non-compressible, then the mass of fluid flowing into a controlled volume must equal the mass out of a controlled volume. Water and oil are examples of non-compressible fluids. If a fluid is compressible, the mass of fluid put into a controlled volume can differ from the amount of mass removed from the controlled volume. Gas flow is the most common example of a compressible fluid.

504-13.2.3 "RANGEABIALITY" OR "TURN-DOWN RATIO". ″Rangeability″ or ″turn-down ratio″ is a term used to describe the ratio of the maximum flow rate to minimum flow rate which can be accurately measured by a flowmeter. Rangeability can vary from 4:1 typical of differential pressure meters to over 40:1 for ultrasonic flowmeters. It is a significant factor in the selection of a flowmeter.

504-13.2.4 LAMINAR FLOW. Laminar Flow occurs at relatively low flow rates. At these rates the viscous forces (resistance of fluid particle to change of direction) of the fluid dominate inertial forces. This results in fluid traveling in stable, ordered, laminated planes (see Figure 504–13–1). The viscous effects of the fluid interacting with the pipe wall cause fluid to drag along the pipe wall. Examination of fluid velocity throughout the pipe diameter would reveal that fluid velocity is higher in the center of a pipe than along the pipe wall.

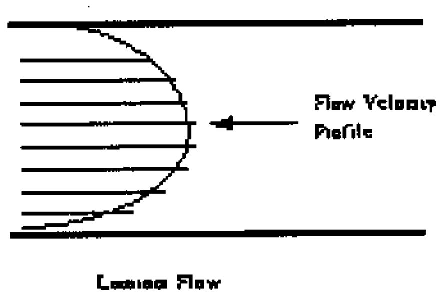


Figure 504-13-1. Laminar Flow

504-13.2.5 TRANSITIONAL FLOW. As fluid velocity increases the inertial forces of fluid particles begin to overcome the viscous strength of the fluid. Thus the laminated layers typical of laminar flow begin to break down (see Figure 504-13-2). The resulting condition is referred to as transitional flow. Also, the flow profile takes on a ″flatter″ shape.

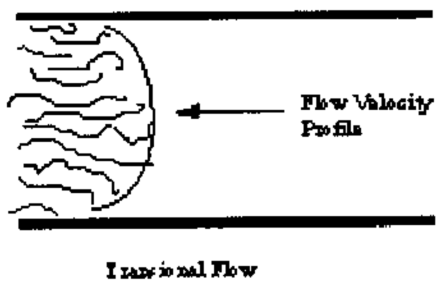



Figure 504-13-2. Transitional Flow

504-13.2.6 TURBULENT FLOW. Turbulent flow occurs at high flow rates when inertia of fluid particles dominates viscous properties of the fluid. Layered flow breaks down and flow profiles take on a more random or ″plug″ flow profile (see Figure 504-13-3).

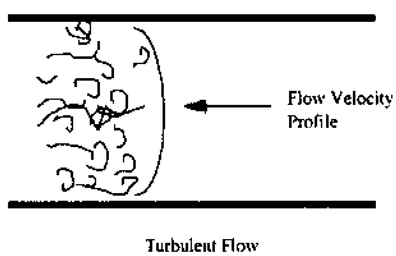



Figure 504-13-3. Turbulent Flow

504-13.2.7 REYNOLDS NUMBER. Because the properties of fluids vary in magnitude to a high extent, it is not possible to specify a velocity in which flow profiles move from laminar to transitional to turbulent. Instead, a dimensionless number has been defined which characterizes the conditions of flow in a pipe. Reynolds number is the ratio of inertial to viscous forces in a flow condition. Calculation of Reynolds Number is:

$$Re = \frac{\rho V d}{\mu}$$

where : Re = Reynolds number
$\rho$ = fluid density (lbm/ft$^3$)
V = fluid velocity (ft/sec)
d = the diameter of the system (ID for pipe, ft)
and $\mu$ = absolute viscosity (lbm/ft/sec)

When the calculated Re is below 2000, flow is considered to be in a laminar region. Flow is considered to be in a transitional region when the Re is between 2000 and 8000. The turbulent flow region dominates when Re exceeds 8000.

504-13.2.8 ACCURACY. Accuracy of a flowmeter may be expressed as percent error or meter factor. Meter factor is the ratio of Actual Flow to Measured Flow. Percent error can be expressed in terms of percent of actual flow (indicated value), or as percent of span (full scale). Percent of actual flow implies that the percent error compares the measured flow to the actual flow, i.e., at 4 ft/sec a 1% accuracy would mean that the flow value was between 3.96 ft/sec and 4.04 ft/sec. When percent of span is designated, the value of error calculated at the maximum flow rate is applied to the entire flow rate range. Using our previous 4 ft/sec flow rate and a flowmeter with a 10 ft/sec span, at 1% the actual flow value could be between 3.9 ft/sec and 4.1 ft/sec. Using a percent of span flowmeter is only recommended when the anticipated flow rate is in the upper 10% of the flowmeter's span.

504-13.2.9 LINEARITY. Linearity is a measure of the stability of a flow meter over a specified flow rate range. It is calculated as the ratio of the difference between the maximum meter factor and minimum meter factor to the average meter factor. Linearity is generally expressed as a percentage.

504-13.2.10 REPEATABILITY. Repeatability is a measure of the stability of a flow meter under a specified set of flow conditions. Accuracy is determined several times under consistent flow conditions. The maximum deviation of accuracy is calculated as a percentage and is termed repeatability.

## 504-13.3 SAFETY

504-13.3.1 LEAKS. When installing and operating flow meters in petroleum systems, make certain that no leaks exist. A leak constitutes a fire and explosion hazard.

504-13.3.1.1 Fuel Oil or JP5. When meters with electrical registers are used they shall be of an intrinsically safe design. The flowmeter shall be located in an open or ventilated space.

504-13.3.1.2 Gasoline. Meters with self-contained direct reading mechanical registers must be used for gasoline service. Any register requiring an electrical supply is not permitted unless it is certified as intrinsically safe for gasoline use.

504-13.3.2 When cleaning meters with solvents be sure there is adequate ventilation to avoid direct breathing of vapors. Wear rubber gloves to prevent skin contacts with the solvent.

504-13.3.3 Flowmeter design should maintain the designed compliance with the ships piping system requirements. Although pressure rating, material, welding joint design, etc. for ships piping systems are discussed in MIL-STD-777(SH), sound work practice dictates that you replace a defective flowmeter only with the same model manufacturer or stock number.

## 504-13.4 TOTAL FLOW METERS

### 504-13.4.2 POSITIVE DISPLACEMENT METERS

504-13.4.2.1 Description. Positive displacement meters operate by admitting and discharging a fixed amount of fluid through a chamber of known volume. The number of fillings are counted to obtain a measure of total fluid volume flowing over a given time period.

504-13.4.2.2 Typical Model. The positive displacement meter commonly used by the Navy incorporates a nutating disc to separate the volume of liquid flowing through the meter body. The disc is mounted in a circular chamber having a conical roof and floor. A vertical partition restricts the disk from spinning about its own axis, but allows the disk to nutate (wobble) when fluid enters the chamber. The nutating action divides the chamber into two compartments which are successively filled and emptied with each nutation. The vertical partition also acts to divide the inlet and outlet flows. In operation, the shaft on which the disc is mounted travels in a circular motion. This motion is transmitted by a gear train to the meter register which totalizes revolutions. Each rotation of the primary device represents a fixed volume. The secondary device translates pulses generated with each rotation into total volume. A positive displacement meter is illustrated in Figure 504-13-4.

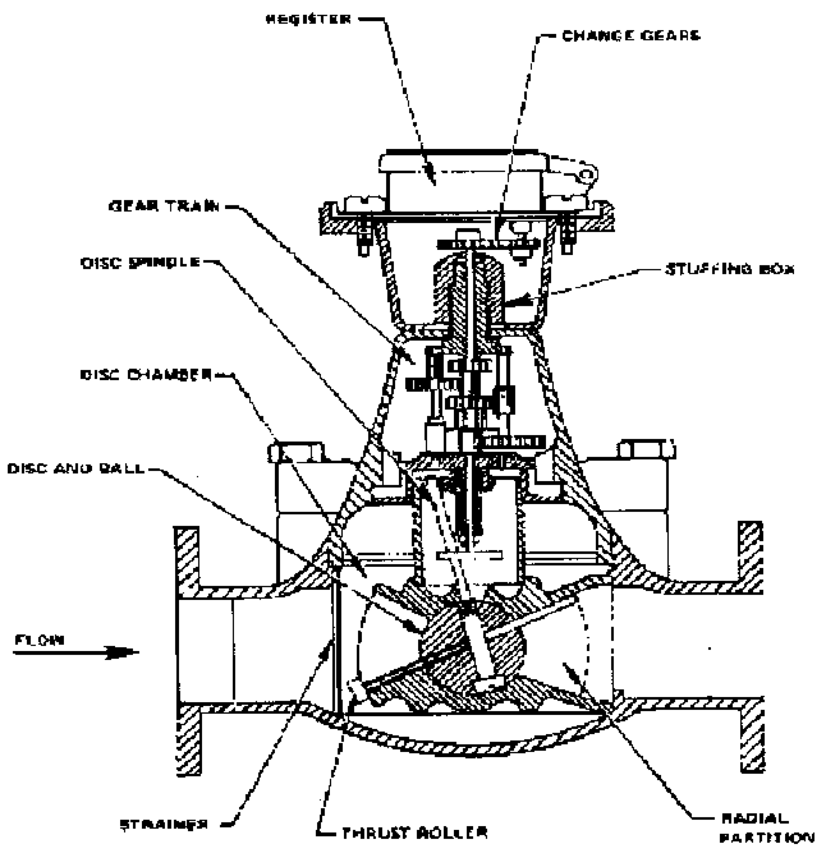



Figure 504-13-4. Positive Displacement Flowmeter

504-13.4.2.3 Installation. Positive displacement meters are used to measure the quantity of flow of such homogeneous liquids as water, fuel oil, petroleum products, and chemical solutions. Fluids containing dirt or foreign material interfere with the motion of the nutating disk. Positive displacement meters are therefore not recommended for dirty applications.

504-13.4.2.4 Meter Classification. Classification of water meters specified for naval use is as follows:

504-13.4.2.4.1 Cold water meters, for water temperatures up to 37.8°C ( 100°F), are generally specified as ±2 percent of actual volume with a rangeability of 20:1.

504-13.4.2.4.2 Hot water meters, for water temperatures up to 82.2°C (180°F), are generally specified as ±3 percent of actual volume with a rangeability of 4:1.

504-13.4.2.4.3 A detailed discussion of positive displacement fuel oil meters may be found in NSTM Chapter 541, Ship Fuel and Fuel Systems. The information given may be applied to water and chemical meters as well. It is important to use the correct size meter for the flow range to be measured regardless of the system pipe size.

504-13.4.2.5 Operation. Positive displacement meters require no special operating procedures. The flowmeters operate without electrical power. Visual readings of the flow total is all that is required.

504-13.4.2.6 Maintenance. The flowmeter should be checked to make sure the register face is not cracked or broken. Inspect the meter during operation to ensure flow is being totalized. The gearing can wear and cause meter failure. Partial wear of the gearing will be detected during calibration. The stuffing box nut should be hand tightened just enough to stop leakage. Over-tightening will result in premature failure of the gear train.

504-13.4.2.7 Calibration. The most accurate way to calibrate the positive displacement meter is to pass a measured amount of liquid through it at a controlled rate. This is usually done on-site in-place using a standard container for flow totalizers measuring low flow rates. A standard flow system is used for high flow rate flowmeters. It supplies a liquid of known specific weight which is collected and weighed after being run through the meter for a measured time. Its volume and rate are then calculated and compared with the meter register readings to obtain a percentage error at a given rate. Several criteria for this test are:

504-13.4.2.7.1 The meter should be tested with the liquid it is to meter (or one of similar characteristics) and at nearly the same temperature at which it will be used. This is because temperature will affect both the dimensions of the meter and the viscosity and density of the liquid.

504-13.4.2.7.2 The meter should be tested at several rates over the range at which it will be used.

504-13.4.2.7.3 The liquid should be free of entrained air or vapor (these will be registered as liquid).

504-13.4.2.7.4 The volume of the reference container should be at least sufficient to hold the quantity which will pass through the meter in 1 minute when the meter operates at its maximum rated capacity.

504-13.4.2.7.5 The only method for adjusting this type of a register indicator to coincide with the actual quantity over a considerable portion of the operating range is to change the gear ratios of the meter. This is not done by outside design and overhaul activities. Instead, during calibration, correction factors curves are plotted of the meter indication versus the actual flow rate. Using the correction factor curves and the meter's actual reading, operating personnel can compute the true values of the measured medium.

504-13.4.3 TURBINE METERS

504-13.4.3.1 Description. Fluid traveling through a turbine flowmeter forces the primary device (turbine) to rotate at an angular velocity proportional to the rate of flow. The number of rotations is proportional to the total volume passing through the flowmeter. This type of flowmeter does not physically separate fluid into discrete volumes (like a positive displacement meter), but infers total volume from the reaction of fluid on the primary device.

504-13.4.3.1.1 A typical turbine meter is illustrated in Figure 504-13-5. The number of rotations of the primary device can be transferred to the secondary device either electrically or mechanically. However, typical turbine meters used for Navy application incorporates magnetically marked turbine blades. When these blades pass a pickup coil, an electrical pulse is generated and detected by the secondary device. In this respect, turbine meters generate a pulse which indicates total quantities and not rates of flow. Flow rate can be implicitly derived from the frequency of pulse generation. The turbine need not take up the whole cross section of the meter tube. Thus fluid can pass with little obstruction.

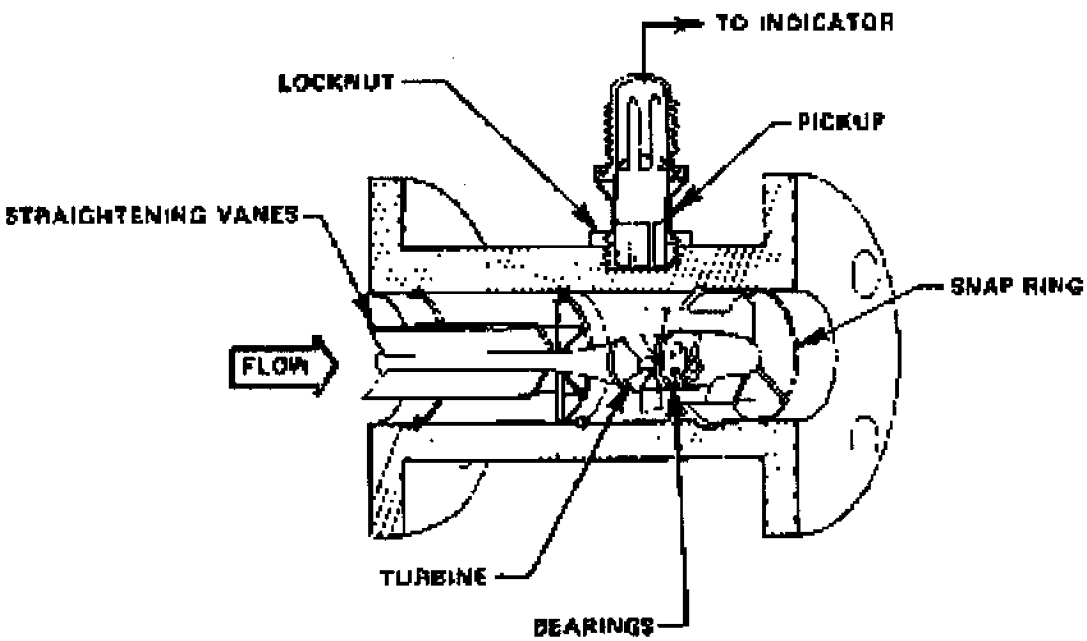



Figure 504-13-5. Turbine Flow Meter

504-13.4.3.1.2 The meter factor, or K factor, of the turbine meter represents pulses per unit volume, usually pulses per gallon. Ideally the K factor would be constant over the entire measured flow rate range. However, the typical K factor curve is an extended horizontal ″S″ shape. An example of a typical K factor curve is displayed in Figure 504-13-6. Fluid viscous effects and bearing friction effect to lower flow rate ranges causing the curve to drop steeply. Bearing overspeed and high pressure drop encountered at high flow rates cause the curve to rise steeply. The flow rate portion of the K-factor curve which meets the specified linearity requirements determines the rangeability of the flowmeter. Typical rangeability of turbine flowmeters is 13:1.

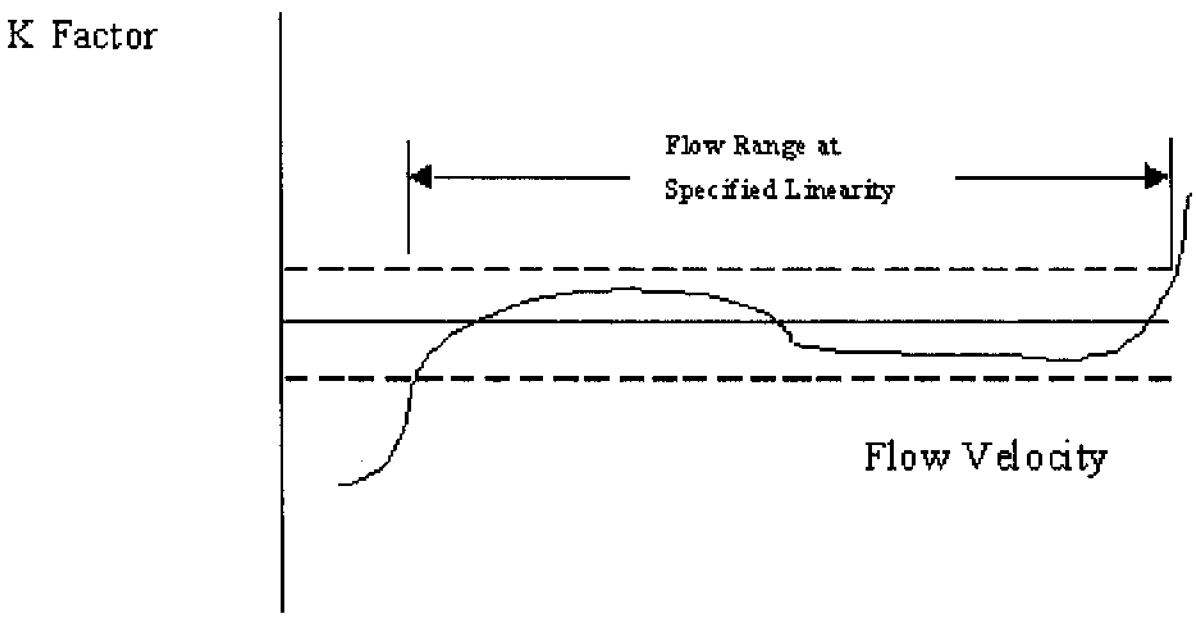



Figure 504-13-6. K Factor vs Flow Velocity

504-13.4.3.2 Installation. Turbine flowmeters are among the most common sensors used for fluid measurement by the Navy. The turbine flowmeter housing can be either threaded or flanged. Specific design shall be in accordance with system requirements. Flowmeter sizing requires that the fluid type, pressure, composition and anticipated flow rate range be specified.

504-13.4.3.2.1 Turbine flowmeters can be used for liquid or gas applications. Dirty fluids are not well tolerated as solids can foul the rotor bearings and affect the meter's accuracy. Also, solids can lodge between the turbine and the housing and cause the turbine to ″lock-up.″ Rotor blades must be specifically sized to allow particles to pass through the sensor. Changing the blade clearance will affect both the accuracy and rangeability of the system.

504-13.4.3.2.2 Selection of the bearing material will significantly affect the life and performance of the turbine flowmeter. Bearing material is primarily dependent on fluid type and required accuracy.

504-13.4.3.2.3 The rotor assembly can generally be replaced. However, the accuracy of the turbine flowmeter is specific to the rotor assembly. The meter K factor must be reset if the rotor assembly is replaced.

504-13.4.3.2.4 To ensure accurate flow measurements, it is essential that the fluid enter the meter free from swirls or vortices. Such disturbances will be minimized by the use of specific lengths of straight pipe, both preceding and following the meter called flow straightener. The function of flow straighteners is to stabilize the flow profile prior to passage through the rotor, and to minimize the required straight run of pipe for system accuracy. The guidelines for the minimum length of flow straighteners are: (a) a pipe length of 10 times the pipe diameter is required for upstream flow straighteners; (b) a pipe length of 5 times the pipe diameter is required for downstream flow straighteners. Flow straighteners are commonly included in the flowmeter housing.

504-13.4.3.2.5 Before installation, place the meter in a horizontal position and blow into the inlet port. The rotor should spin freely with no evidence of roughness or binding.

504-13.4.3.2.6 The meter is mounted in the piping line just as though it were a short length of pipe. Meters may be operated in any position but the favored installation is horizontal.

504-13.4.3.2.7 Observe the flow direction arrow on the meter when making an installation. The propeller must face the oncoming flow.

504-13.4.3.2.8 In newly installed or modified piping systems, the line must be flushed before the meter is installed to minimize possible damage from foreign materials.

504-13.4.3.2.9 The cable from the pick-up coil to the remote reading indicator should be shielded and grounded at the readout. Avoid running the cable alongside power cables or electric meters. Where very long runs or runs parallel to power lines cannot be avoided a signal preamplifier is required. This boosts the flowmeter signal above any electrical noise and extraneous pulses.

504-13.4.3.3 Operation. Operation of turbine flowmeters is entirely automatic (assuming power is properly supplied) except where a reset or incremental totalizer is included on the indicator. This must be hand set on zero at the start of a run.

**CAUTION**

**Operation of turbine flowmeters is entirely automatic (assuming power is properly supplied) except where a reset or incremental totalizer is included on the indicator. This must be hand set on zero at the start of a run.**

504-13.4.3.3.1 Check that the indicator is functioning after flow has started through the meter.

504-13.4.3.3.2 The liquid being metered should be free from foreign materials which could foul the meter and it should be free of entrained air which will cause an inaccurate reading.

504-13.4.3.4 Maintenance. Inspect moving parts of the meter for smooth operation and lubricate at prescribed time intervals according to the recommendations of the meter manufacturer.

504-13.4.3.4.1 Where spare parts are available, repairs and replacements should be made only by experienced instrument repair personnel. In some cases it is advisable to replace the entire meter and return the faulty one to the manufacturer.

504-13.4.3.4.2 Whenever a rotor assembly is replaced, the meter must be re-calibrated.

504-13.4.3.4.3 When the meter is disassembled, clean all metal parts with solvent. Do not use solvent on the turbine if it is made of plastic, but carefully clean and scrape the propeller so the blades offer smooth surfaces to the flow.

504-13.4.3.5 Calibration. Essentially the methods and procedures used to calibrate turbine flowmeters are the same as those for positive displacement meters, as described in paragraph 504-13.4.2.7.

504-13.4.3.5.1 Turbine flowmeters are calibrated by passing a measured amount of liquid through it at a controlled rate. This is usually done with a flow system whereby a liquid of known specific weight is collected and weighed after being run through the meter for a measured time. The total pulses generated by the flowmeter and the total volume passed through the flowmeter are divided to generate a K factor. This process is repeated at several flow rates to determine accuracy and the rangeability. Several criteria for this test are:

1. The meter should be tested with the liquid it is to meter (or one of similar characteristics) and at nearly the same temperature at which it will be used. This is because temperature will affect both the dimensions of the meter and the viscosity and density of the liquid.
2. The meter should be tested over the range of rates of flow at which it will be used.
3. The liquid should be free of entrained air or vapor because these will be registered as liquid.
4. The volume of the reference container should be at least sufficient to hold the quantity which will pass through the meter in 1 minute when the meter operates at its maximum rated capacity.

504-13.4.3.5.2 Accuracy of ±0.5 percent of flow rate may be achieved by turbine flowmeters in clean liquid service at steady specific gravity and viscosity.

504-13.4.3.6 Anemometer. A particular type of gear-driven propeller meter deserving brief mention is the anemometer. This meter is similar to a turbine flowmeter except that the turbine is replaced with a propeller, and the number of rotations is mechanically transferred to the secondary device. Anemometers are used to measure air and gas flows, usually indicating in ft/min.

## 504-13.5 VELOCITY FLOWMETERS

504-13.5.1 GENERAL. Velocity meters are used to measure the current velocity of fluid in a system. The velocity may be integrated to determine total flow over a period of time. Velocity flowmeters discussed in this section shall include head-producing, variable area and powered flowmeters.

504-13.5.2 HEAD PRODUCING FLOWMETERS.

504-13.5.2.1 Description. The distinctive feature of head meters such as the venturi tubes, orifice meters, elbow meters, flow nozzles and pilot tubes, is that the primary device causes a marked change in the static pressure of the fluid while it is passing through the meter. The secondary device detects the change in static pressure and scales the differential pressure in terms of flow rate. The venturi tube and orifice meter are the most commonly used head producing meters in shipboard applications. They are used on systems such as fuel flow transfer, air systems and chilled water for air conditioning.

504-13.5.2.2 Function. The function of an orifice plate or a venturi tube is to accelerate fluid through a restricted area. The acceleration creates a pressure drop across the primary device. Fluid velocity is proportional to the square-root of the pressure differential caused by the primary device. This relationship is described by Bernoulli's equation. Solution of the equation becomes somewhat empirical and is dependent on the flow regime and fluid compressibility. The various solutions to the Bernoulli equation are beyond the scope of this reference.

504-13.5.2.3 Typical Plate. Thin plate, concentric orifice plates are the most frequently used type of orifice plate. They are installed between flanges. Typically the flanges will have pressure taps. The orifice plates can be easily replaced and are inexpensive. Figure 504–13–7 displays a typical orifice meter configuration.

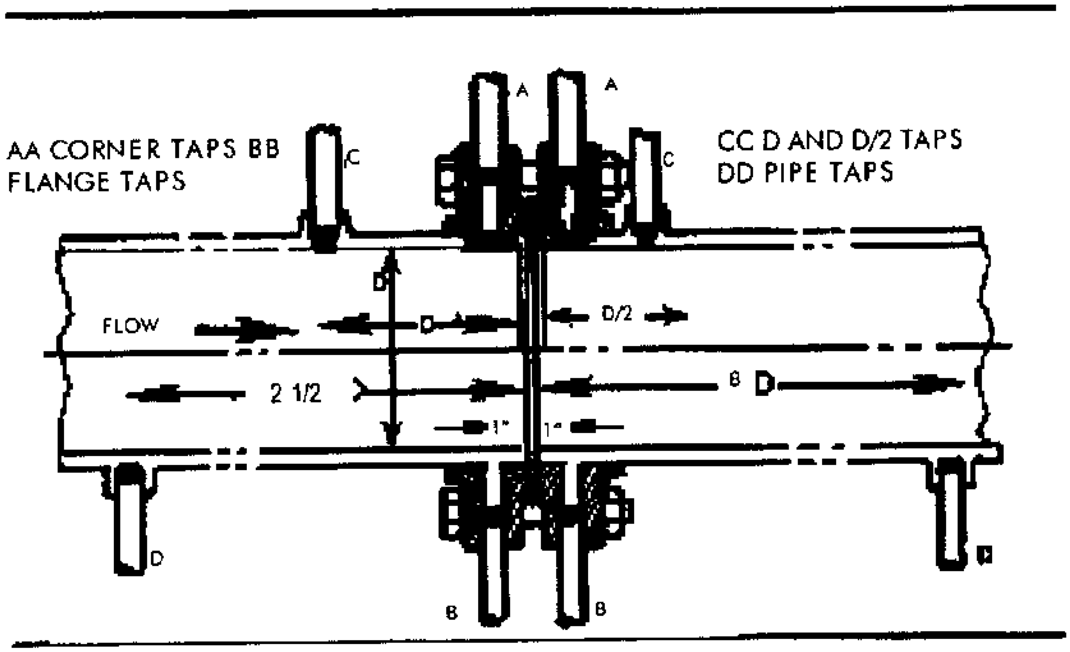



Figure 504-13-7. Typical Orifice Meter Configuration

504-13.5.2.4 Venturi Tube. A venturi tube is shown in Figure 504–13–8. The venturi tube is made up of a short constricted portion between two tapered sections and is usually inserted between two flanges in a pipeline. Pressure connections are provided for observing the difference in pressures between the inlet and the constricted portion, or throat. The straight inlet, entrance cone, straight constricted portion or throat, exit cone, and outlet are all joined by curved surfaces. This reduces resistance, minimizes wear, and ensures a smooth, full flow. Static pressure of the fluid at the inlet and throat may be obtained through a single side wall hole, or through several holes evenly spaced around the section leading into a piezometer ring from which a single connection is made. The throat and inlet portion are always machined or cast very smooth; exact determination of their diameters is essential to the precise measurement of flow by the meter.

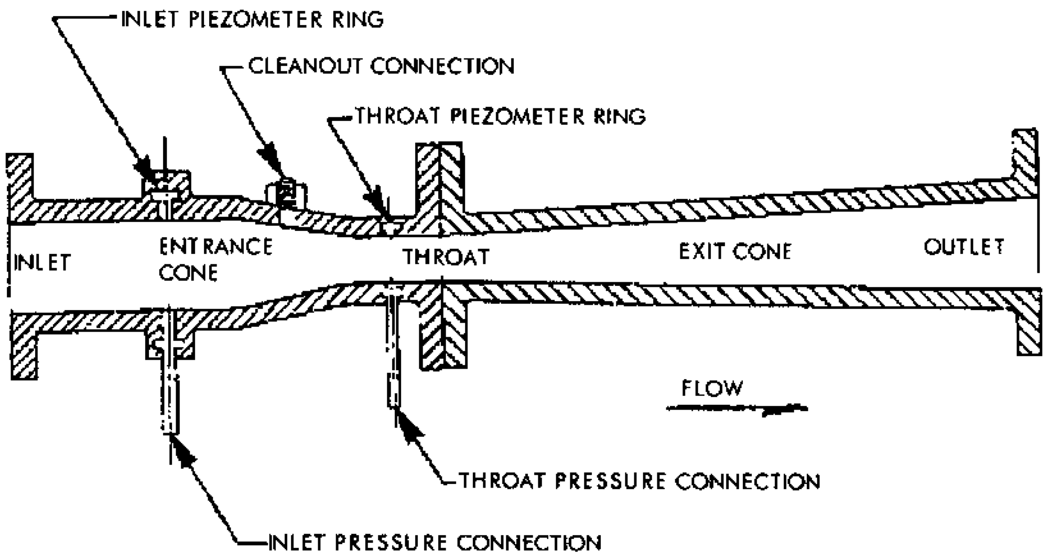



Figure 504-13-8. Venturi Tube

504-13.5.2.5 Reversible Flow Tube. One modification of the basic venturi tube is the reversible flow tube where flow in either direction may be measured. The tube is made symmetrical with a throat tap at the center and an inlet tap at each end. A differential pressure sensor is connected to each inlet tap and to the throat tap. With both sensors on the line, flow direction is indicated by the highest reading.

504-13.5.2.6 Differential Pressure Measurement. The secondary device detects the pressure differential created by the primary device. Differential pressure from the taps may be measured by any common differential pressure element. Most instruments either indicate or record the differential head, or are scaled in units of flow rate such as ft3/min or gal/min.

504-13.5.2.7 Rangeability and Differential Pressure. Sizing of head producing fluid flowmeters requires thorough knowledge of the system. The rangeability of orifice meters is approximately 4:1, and the rangeability of venturi systems is approximately 6:1. The ratio of the pipe constriction Inside Diameter (ID) to the pipe ID is termed **beta ratio** (β). The β is critical in establishing rangeability and resulting differential pressure. Venturi meters have an advantage in producing a higher rangeability, and a higher pressure recovery (the final pressure loss is higher for an orifice meter than a venturi tube). Venturi tubes are more expensive and can be heavy, especially in large pipe applications.

504-13.5.2.8 Flow Straightener. A long continuous run of straight pipe (13 diameters minimum upstream and 5 diameters minimum downstream) must be provided to obtain accurate results from a head producing meter. The upstream distance may be lessened by use of a flow straightener, such as a tube bundle or straightening vanes. The flow straightener should be installed some distance upstream of the meter to avoid influencing its differential pressure relationship to flow rate.

504-13.5.2.8.1 Excessive pipe roughness or heavy sediment must be avoided; these will cause inaccuracies of the flow indication.

504-13.5.2.8.2 The meter is installed in the line as a section of pipe with flanged connections. Pressure taps are usually 1/4-inch tube or 1/4-inch IPS.

504-13.5.2.8.3 The preferred installation or pressure tap lines should provide a three-valve manifold assembly similar to that used for manometers, so that a zero setting can be obtained on the differential pressure sensor. In liquid systems an air bleed should also be provided for venting the sensor to ensure a complete liquid fill.

504-13.5.2.9 Operation. Once installed, head producing flowmeters operate automatically whenever flow exists. If a differential pressure gage is used as the secondary device, no electrical power is required for operation. Differential pressure transducers can be used for the secondary device if remote indication is required. Be sure the transducer is energized when readings are to be taken. If valves are located in the pressure tap lines, ensure that they are open. When an air bleed is provided on liquid system sensors, vent the system before taking a reading. When a three-valve manifold is provided, set the sensor to zero before taking a reading.

504-13.5.2.10 Maintenance. No general maintenance of head producing flowmeters is required. Periodically check the condition of the inside surface of the primary device. If this becomes worn, rough, or eroded, the element must be replaced. Check the holes leading to the pressure taps for signs of clogging. Carefully clean them out when necessary. For some venturi tubes installed on fuel oil systems, two pipe taps may be installed on the entrance section to which steam and drain lines may be attached. A few minutes steaming out will clean the chamber surrounding the throat and the pressure taps. The small amount of condensed steam which enters the flow line will settle in the storage tank to be drained off with the sediment.

504-13.5.2.11 Calibration. Calibration of head producing flowmeters should be accomplished only by the manufacturer or a suitable naval laboratory.

504-13.5.3 VARIABLE AREA METERS

504-13.5.3.1 Description. Variable area meters are constructed so that the area of flow varies to hold the differential pressure through the primary device constant. The differential pressure is maintained constant by a free-floating element which rises and falls as the flow rate changes. The float rises until its weight is balanced by the force of the flowing fluid. The metering cross sectional flow area is increased as float rises. Therefore, the height of the float can be translated to an indication of rate of flow.

504-13.5.3.2 Tapered Tube and Float Type (Rotameter). The most widely used form of variable area meter is the tapered tube and float or rotameter which is shown in Figure 504–13–9. A float is suspended in a vertical tapered tube and moves axially with the flow, the flow being vertically upward. The weight of the float, minus its buoyancy in the fluid, is balanced by the drag force of the fluid upon the float. The float rides at a height that will maintain this balance of forces. The float is generally kept centered by internal flutes or ribs in the tapered glass tube or by the use of a guide rod extending the vertical length of the rotameter. Generally, glass is used for the tube material, but plastic and metal are also employed. Glass and clear plastic tubes have a scale etched on them and the position of the float may be directly determined. With metal tubes, indirect means are provided to observe the position of the float. One method uses a rod attached to the float and passes through a casing tube. A magnetic follower over the casing indicates the fluid flow rate on a vertical scale above the meter.

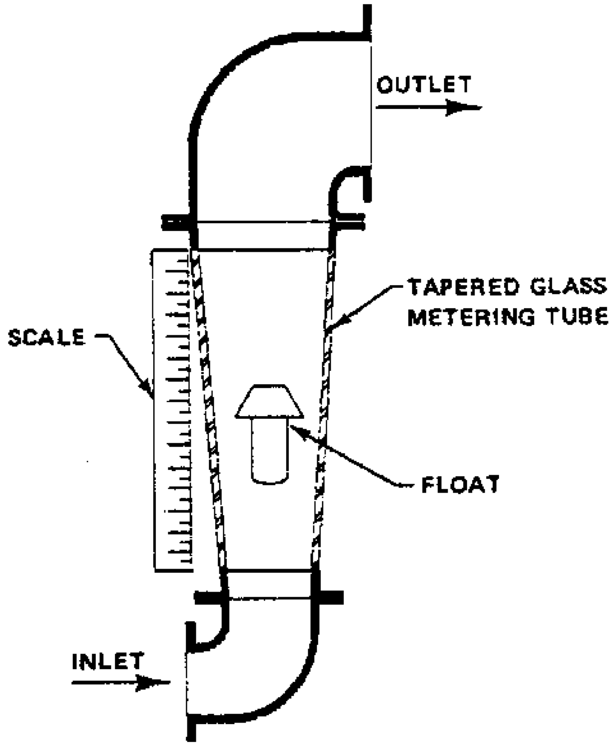



Figure 504-13-9. Tapered Tube and Foat Type-Rotameter

504-13.5.3.2.1 The tube is graduated either in flow rate or in percent of full flow with an additional external metal scale calibrated in flow rate mounted beside the tube. When the scale is graduated only in flow rate, the meter is intended for measurement of a fluid of a given density. Fluids of other densities will change the buoyancy of the float and therefore cause errors in flow rate indication. When the scale is graduated in percent of full flow it may be used to measure fluids of various specific weights as long as calibration curves for the fluids are available to interpret the meter readings.

504-13.5.3.2.2 The shape and material of the float may vary considerably depending on the physical properties of the fluid being metered. A thin disc float will be almost independent of fluid viscosity changes, while a bullet-shaped float is only slightly affected by the dynamic forces due to the motion of the fluid. To overcome small changes in fluid specific weight, the float should be of a material that is about twice as dense as the fluid being measured. Standard accuracy of rotameters is in the order of ±2 percent of full scale.

504-13.5.3.3 Cylinder and Piston Type. Another variable area flowmeter is the cylinder and piston type as shown in Figure 504–13–10. Operation is in many ways similar to that of the rotameter. The difference is that the area for fluid flow is provided by a series of reamed holes in the walls of the cylinder. These holes are spaced in a uniform helical pattern so the variation in area is continuous for various heights of the moving element, which is a loosely-fitted piston. The movement of the piston may be regulated by a weight and dash pot or a spring. With properly spaced holes in the cylinder, the calibration of the instrument for flow rate is linear. A similar design replaces the multiple holes by one or more longitudinal slots in the cylinder.

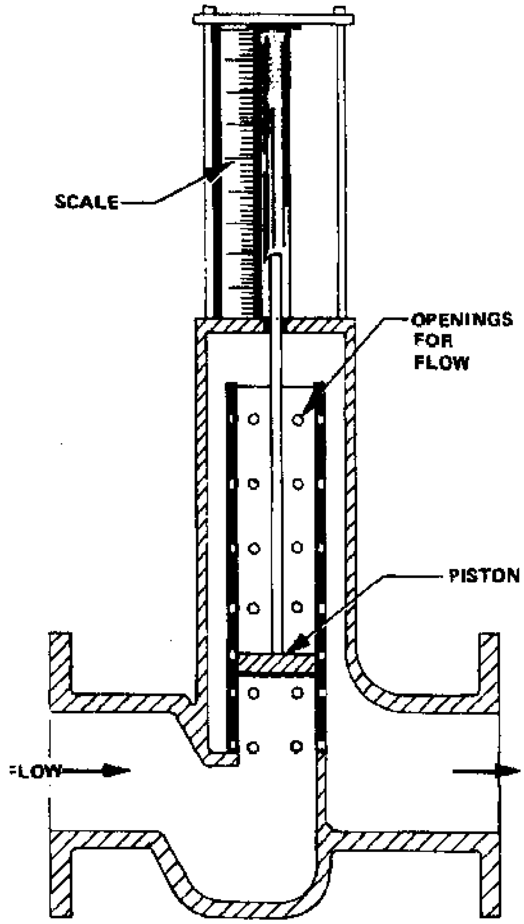



Figure 504-13-10. Cylinder and Piston Type Flowmeter

504-13.5.3.3.1 A rod attached to the top of the piston moves inside a sight glass mounted above the cylinder. The position of the piston rod indicates flow rate on a suitable scale.

504-13.5.3.3.2 The cylinder and piston meter is most often employed to measure flow of heavy fuel oils, chemical liquids, and other high viscosity fluids. It is especially useful for applications where corrosion and clogging of head meter elements is likely to occur or where adequate information is not available on flow coefficients at low Reynolds numbers. In both the rotameter and cylinder and piston meter, the indicating rod may be provided with an armature to move in a double solenoid through which an inductance bridge system is employed for remote indication and recording of flow rate.

504-13.5.3.4 Installation. Rotameters must be installed vertically with the outlet and the highest scale graduation at the top. Cylinder and piston types must also be installed with the cylinder and piston vertical so the piston moves up with increased flow. Use a plumb bob or equivalent device to check vertical alignment.

504-13.5.3.4.1 Installation is made with standard pipe connections. The cylinder and piston meter is usually constructed with the inlet and outlet in line so it may be installed in a straight horizontal section of pipe. The rotameter has an inlet at the bottom and an outlet at the top and the piping must be arranged to accommodate this configuration.

504-13.5.3.4.2 In general, when a meter is to be used for gas service it should be located as close as possible to a throttling (gas flow adjustment) point but preferably with the valve located at the output fitting. Inlet pipe size for gas service should be kept to a minimum. For liquid service, however, piping should be as large as economically practicable.

504-13.5.3.4.3 Small meters generally will be supported adequately by the connecting piping, but larger sizes may need additional external supports.

504-13.5.3.4.4 Simple direct readout meters require no electrical or air service.

504-13.5.3.4.5 For rotameters, plastic or metal metering tube types should be used instead of glass wherever possible.

504-13.5.3.5 Operation. Operation of area meters is virtually automatic but the points listed in this paragraph should be noted:

1. Start flow through the meter gradually to prevent too great an initial surge that might damage the float or piston assembly. First establish flow through the bypass, slowly open the meter valves, and then slowly close the bypass.
2. Check that the indicator is functioning after flow has begun.
3. All air or vapor must be vented from the meter and pipe line when metering a liquid.
4. On rotameters, make certain that readings are taken from the scale at the graduation coinciding with the reading edge of the float.
5. Keep the fluid being metered free from foreign material.

504-13.5.3.6 Maintenance. Area meters are fairly maintenance free except that the flow tube or cylinder should be cleaned at regular intervals by swabbing it out with a suitable cleaning solution.

504-13.5.3.6.1 When the meter is to be disassembled, the manufacturer’s detailed instructions should be followed. Be careful not to drop or in any way damage the float or piston because accuracy of the meter depends on the float remaining stable in weight and shape.

504-13.5.3.6.2 At re-assembly, align the metering tube or cylinder exactly to its original position relative to the scale.

504-13.5.3.7 Calibration. The area meter may be calibrated by the same method as described for positive displacement meters. A measured amount of liquid is passed through the area meter at a given rate, see paragraph 504-13.4.2.7.

504-13.5.3.7.1 If the specific weight of the fluid used in making the calibration is the same as the fluid to be metered, the calibration will apply directly. However, when the fluid to be metered has a specific weight different from that of the fluid used in the calibration, this difference should be taken into account, especially in the metering of gases.

## 504-13.5.4 POWERED FLOWMETERS

504-13.5.4.1 General. Powered velocity flowmeters require that energy is placed into the fluid stream. The energy could be in the form of a magnetic field, a sonic beam, heat, etc. The interaction of the fluid on the added energy is measured.

504-13.5.4.2 Electromagnetic Flowmeterl. Electromagnetic flowmeters are full opening flowmeters which have the design advantage of requiring no moving parts. The primary device (sensor) is constructed as a piece of electrically insulated seamless pipe. The only penetrations into the pipe are two insulated electrodes which contact the process fluid. Two coils that generate a magnetic field are located outside the pipe (contained within a non-corrosive liner) and are located in a position rotated 90° to the electrodes. The pressure loss through the sensor is the same as for an equivalent length of pipe with the same inside diameter. The fluid must be electrically conductive for operation of the flowmeter. The fluid may be heterogeneous making the flowmeter a good choice for slurry or dirty applications. Figure 504–13–11 displays the electromagnetic flowmeter principle.

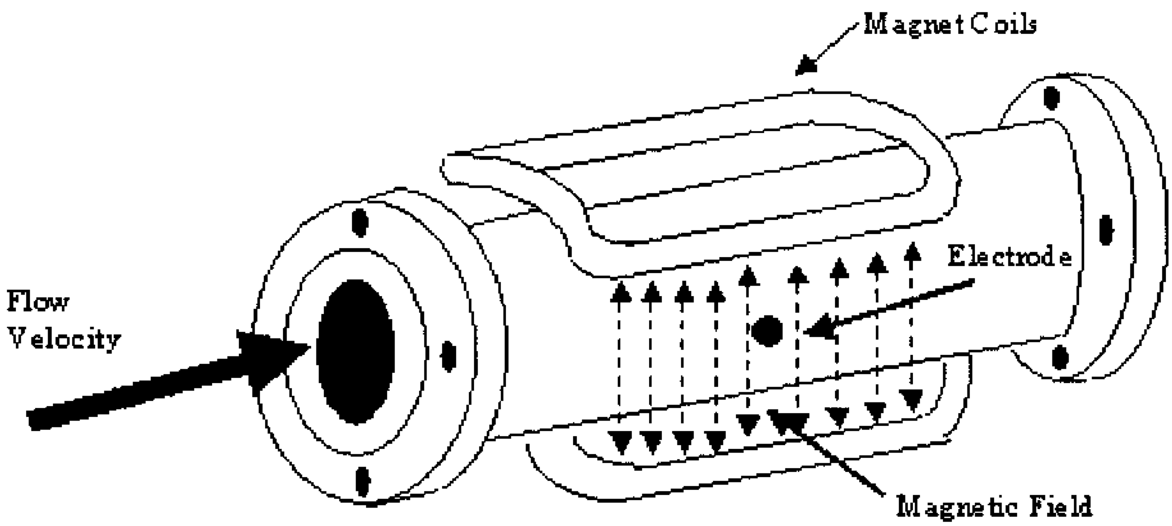



Figure 504-13-11. Electromagnetic Flowmeter Principle

504-13.5.4.2.1 Operation. Operation of an electromagnetic flowmeter is based on Faraday's Law. This law states that an electrically conductive material moving through a magnetic field will generate an electric voltage which is proportional to the speed of the conductor. Expressed mathematically:

$E \propto VBD$,

where:

E = the induced electric voltage

V = the average fluid velocity

B = the magnetic field strength, and

B = the magnetic field strength, and

504-13.5.4.2.1.1 The magnetic field can be produced by an alternating current (ac) or by a pulsed direct current (dc). It should be noted that an electrical voltage is also generated if the magnetic field strength changes in the presence of a conductive fluid (even if the fluid is not moving). The electric voltage due to fluid moving through the magnetic field is in phase with the magnetic field. The electric voltage produced by a changing magnetic field in the presence of the conductive fluid is 90° out of phase with the magnetic field. The variation of these two electrical voltages is called ″quadrature.″ Quadrature adjustments are required for ac powered sensors. Build up of scale or debris on the electrodes will affect the quadrature; therefore, a method of cleaning the electrodes must be provided for ac sensors.

504-13.5.4.2.1.2 The secondary device measures the voltage detected by the electrodes. This voltage is directly proportional to fluid velocity. The flowmeter then converts fluid velocity to volumetric flow rate or mass flow rate by applying appropriate scaling factors.

504-13.5.4.2.2 Installation. Electromagnetic flow sensors are available in flanged, wafer and insertion configurations. The Navy utilizes flanged configurations to ensure pressure integrity and system accuracy. Pipe supports may be required depending on the size of the flanged sensor.

504-13.5.4.2.2.1 The sensors should be installed in a location which will ensure complete fill in the sensor, and should be located to avoid proximity to high strength electromagnetic or electrostatic fields.

504-13.5.4.2.2.2 Sufficient straight pipe length should be provided to ensure a stable flow profile (normally 10 OD upstream and 5 OD downstream). However, electromagnetic flowmeter are more tolerant of reduced straight pipe lengths than other types of flowmeters.

504-13.5.4.2.2.3 Grounding the sensor is required to eliminate stray currents and voltages in the process liquid. A ″third wire″ is generally used to ground the meter to a pipe flange. The sensor liner electrically insulates the sensor from the process fluid. This liner may be eroded by an abrasive process fluid. A protective orifice may be required in the upstream flange to help protect the liner.

504-13.5.4.2.3 Operation. Once installed, the electromagnetic flowmeter requires little formal operational adjustment. Electromagnetic flowmeters are installed on trim and drain piping systems onboard SSN 637 and SSN 688 Class submarines. Operation of these flowmeters can require that a predetermined weight of fluid be pumped. The user is required to input the desired weight of fluid to be transferred. Electromagnetic flowmeters are also used by the Navy to monitor waste discharge.

504-13.5.4.2.4 Maintenance. Maintenance shall be performed in accordance with the appropriate Planned Maintenance System (PMS) and procedures. The electrodes in ac sensors should be periodically cleaned to minimize drift of quadrature. Most flowmeter systems have a method to clean the sensors without requiring that the sensor be removed from the pipe.

504-13.5.5 ULTRASONIC FLOWMETERS

504-13.5.5.1 Description. Ultrasonic flowmeters measure fluid velocity in a pipe by injecting an ultrasonic beam into the pipe and fluid, and measuring the effect of fluid velocity on the ultrasonic beam. Two classes of ultrasonic flowmeters are produced.

504-13.5.5.1.1 A Doppler flowmeter measures the shift in frequency of the transmitted ultrasonic signal. Objects must be present in the fluid to reflect the ultrasonic beam. These particles could be solids or air bubbles.

504-13.5.5.1.2 A time-of-flight meter measures the length of time required to send ultrasonic signal between two ultrasonic transducers. One transmit time is measured with the signal traveling in an upstream direction, and a second transmit time is measured with the signal traveling in a downstream direction. The difference in transmit times is proportional to the velocity of fluid in the pipe.

504-13.5.5.1.3 Both types of ultrasonic flowmeters can be an integral part of a piping system, or can be non-intrusively installed on existing piping.

504-13.5.5.2 Design. The primary device of an ultrasonic flowmeter is a pair of transducers. Non-intrusive transducers are used in the Navy. These transducers mount to existing piping without requiring contact to the process fluid.

504-13.5.5.2.1 Doppler flowmeters measure the frequency shift of a transmitted signal. This phenomenon is called the ″Doppler″ effect. Common examples of the Doppler effect are the shift in sound (frequency) heard when a train or race car passes a bystander. Transducers are small and easily installed. The system requires that something (solids or air bubble) be present in the fluid to reflect the ultrasonic beam. The accuracy of the flowmeter can be affected by the distribution of particle size in the fluid seam. Slow moving large particles could give a stronger frequency shift than faster moving small particles.

504-13.5.5.2.2 Time-of-flight flowmeters require transducers separated by a specific distance on a pipe. In a no-flow condition, the amount of time required for a signal to travel from a downstream transducer to an upstream transducer is equal to the amount of time required for a signal to travel from the upstream transducer to the downstream transducer. As fluid is pumped through a pipe, the amount of time required for a signal to travel from the downstream transducer to the upstream transducer will increase, while the amount of time required to send a signal from the upstream transducer to the downstream transducer will decrease. This is analogous to swimming with a current versus against a current. The difference in the two transmit times is proportional to the fluid velocity. This system is sensitive to solids and air in the system piping. The time-of-flight flowmeter does investigate the entire pipe diameter flow profile.

504-13.5.5.2.3 For both systems, the pipe properties (size, wall thickness and material) must be known. Also, the fluid properties over the anticipated flow conditions should be known.

504-13.5.5.2.4 The secondary device acquires transducer information and calculates fluid velocity. From the known pipe parameters, the secondary device converts fluid velocity to volumetric flow rate, or mass flow rate (assuming the fluid density is known).

504-13.5.5.3 Installation. The Navy has used only time-of-flight ultrasonic flowmeter as a permanently installed flowmeter. Therefore, the remainder of the ultrasonic flowmeter discussion will be dedicated to this type of flowmeter. Figure 504–13–12 dissplays the time-of-flight ultrasonic flowmeter principle. The flowmeter transducers should be located in a position that ensures sufficient straight pipe (ten pipe ODs upstream and five pipe ODs downstream), an area of the pipe less exposed to cavitation and aeration, and a section of the pipe in which the system pressure is high.

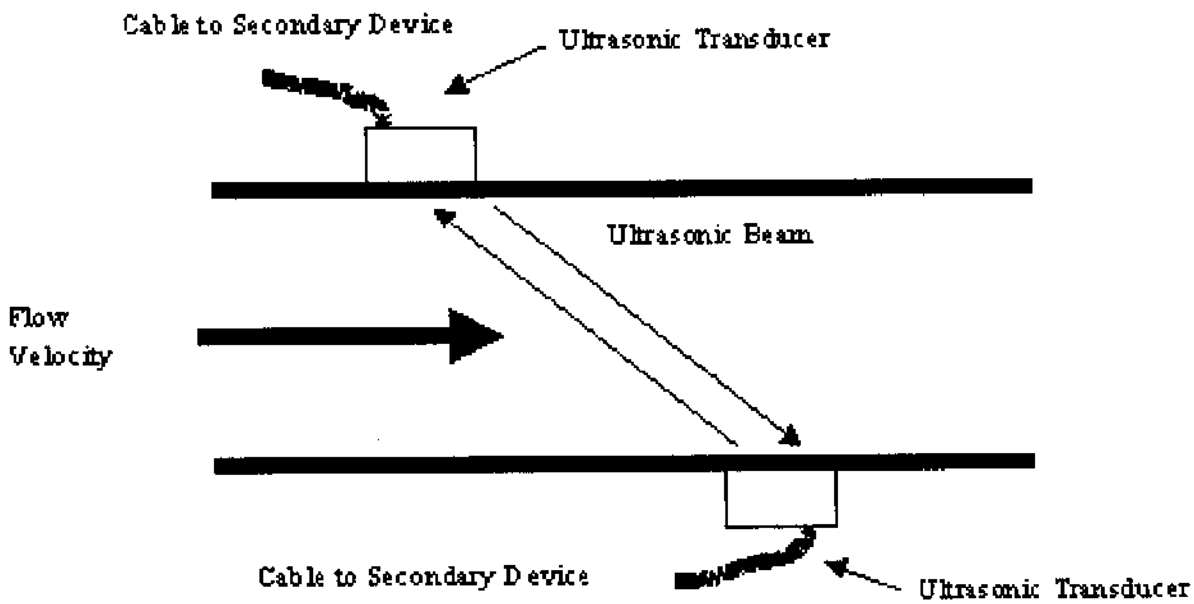



Figure 504-13-12. The Time-Of-Flight Ultrasonic Flowmer Principle

504-13.5.5.3.1 The transducers must have an integral bond to the pipe. The pipe surface should be prepared to a clean finish.

504-13.5.5.3.2 Mounting rails are secured to the pipe. The function of the mounting rails is to establish proper positioning and spacing of the transducers and to secure the transducers to the pipe.

504-13.5.5.3.3 Coupling compound is required to bond the transducers to the pipe and eliminate air from between the transducers and the pipe.

504-13.5.5.3.4 Coaxial cables are generally required to connect the transducers to the secondary device. The secondary device is almost exclusively a processor based flow computer. Programming the flow computer requires knowledge of the flowmeters operating system. Errors entered in programming will be reflected in flow rate determination. Only authorized personnel should accomplish programming the flow computer.

504-13.5.5.4 Operation. Ultrasonic flowmeters are generally configured so that the meter is continuously measuring flow rate. However, accessing the flow computer's operating system may be required to adjust the flowmeter or to correct an error condition.

504-13.5.5.5 Calibration. Ideally, the transducers would be calibrated with the flow computer. If this is not possible, circuit cards that contain adjustable settings which would affect system performance can be removed from the shipboard system and inserted into a control flow computer for calibration. The transducers should be calibrated with the flow computer or the adjustable circuit cards.

504-13.5.5.5.1 Pipe dimensions and material are critical to calibration of the flowmeter. Care must be taken to ensure accurate values of the pipe properties are conditioned into the flow computer.

504-13.5.5.6 Maintenance. The ultrasonic systems should require minimal adjustment and maintenance. It may be necessary to re-bond the transducers to the pipe by applying a new coat of coupling compound. Also, the track and transducers should be checked periodically to ensure they are adequately secured to the pipe.

504-13.5.6 THERMAL DISPERSION METER

504-13.5.6.1 Description. Thermal dispersion meters rely on the cooling properties of moving fluid on the primary device to indicate flow velocity. Figure 504–13–13 displays the thermal dispersion principle. Thermal dispersion meters can be adopted for liquid or gas applications (as long as the fluid is capable of absorbing heat). Most often in Navy applications, the thermal dispersion meters are used in gas flow monitoring.

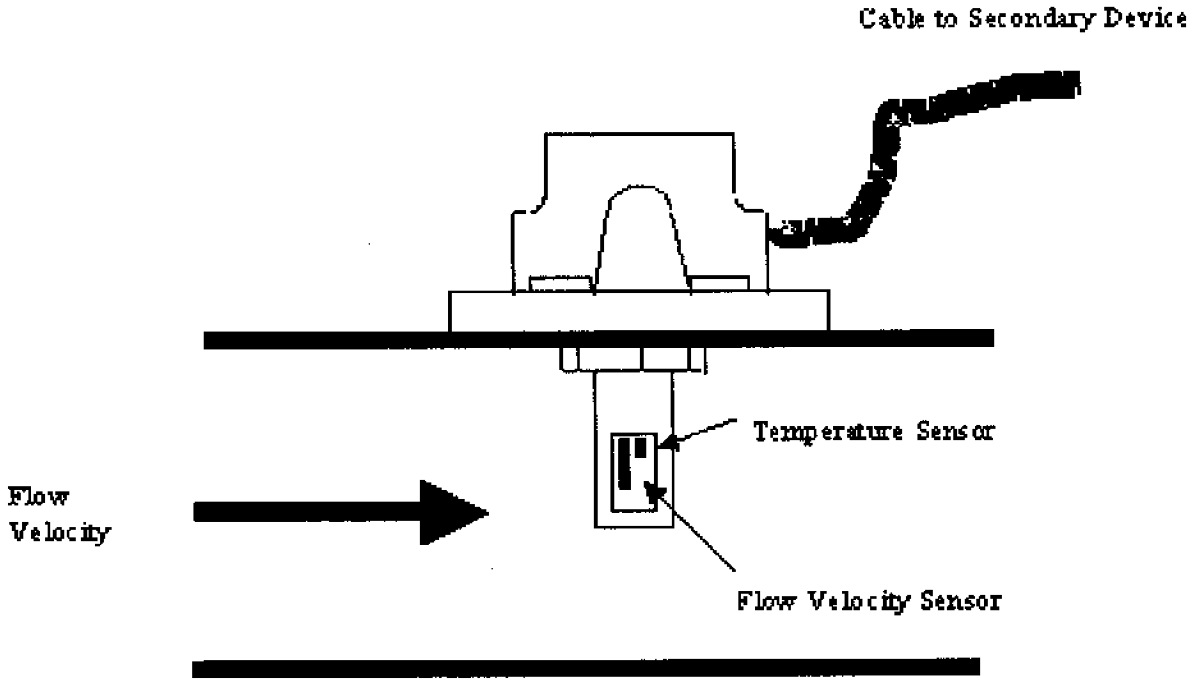



Figure 504-13-13. The Thermal Dispersion Principle

504-13.5.6.2 Operation. The primary device is inserted into the fluid stream. The secondary device supplies and monitors power to the primary device. As fluid removes heat from the primary device, the secondary device will either detect the loss of temperature due to the moving fluid, or will measure the power required to maintain constant temperature of the primary device. Normally maintaining constant temperature of the primary device provides better system performance in terms of response time.

504-13.5.6.2.1 The heat loss of the primary device is proportional to the

a. difference in temperature of the primary device and the fluid

b. fluid density

c. thermal conductivity of the fluid, and

d. velocity of the fluid

Since measured heat loss is a function of fluid velocity and density, the thermal dispersion meter is mass flow sensitive.

504-13.5.6.2.2 System response is generally not linear over the measured flow range. Therefore, a linearizing scheme is required.

504-13.5.6.2.3 Flow velocity detection is especially sensitive at low flow rates. Thus, a threshold minimal flow velocity is generally required for detection of fluid flow.

504-13.5.6.2.4 Once energized, the system requires little operational support. The system may require a warm up period prior to accurate monitoring.

504-13.5.6.3 Installation. The primary device should be located in a portion of the flow stream which represents a normal flow profile distribution. Thus sufficient (ten pipe diameters) upstream and downstream (five pipe diameters downstream) length of straight piping should be available.

504-13.5.6.3.1 The sensing components of the primary element may have to be located a minimal distance from the pipe wall. Thus, the pipe should be of sufficient size to permit required distance from the pipe wall and sufficient velocity of fluid to pass the sensor.

504-13.5.6.4 Calibration. Since the thermal properties of the fluid influence the measured flow velocity, the system must be calibrated in the fluid media to be measured. The effect of the process parameters (pressure, temperature, etc.) must also be known. Thermal dispersion flowmeters generally have a probe to detect the fluid temperature for temperature compensation.

## 504-13.6 CALIBRATION OF FLOWMETERS

504-13.6.1 GENERAL. Flowmeter calibration methods can be classified into three categories: weigh tanks, volumetric provers, and master meters.

504-13.6.1.1 Weigh Tanks. Weigh tanks measure the weight of fluid pumped over a measured time. The weight of fluid is then divided by the density of the fluid to obtain volume. Flow rate should be stabilized before collecting fluid. Weigh tanks should be of sufficient size to permit collection of fluid for several minutes. This will minimize the effects of diverting fluid into and away from the tank during the measurement period.

504-13.6.1.2 Volumetric Provers. Volumetric provers are calibrated volumes. The prover is generally a piston that is valved to permit fluid to pass through before sampling. The valving will close and measure fluid volume upon actuation. The amount of time required to fill the prover is measured. The prover volume is divided by the measured time to produce measured flow rate. The prover volume should be of sufficient size to minimize the effects of the valve actuation on the measured flow volume. Volumetric provers are covered by NAVSEA's Metrology and Calibration Program. Provers are periodically submitted to a Type I calibration laboratory for verification of operating characteristics and specifications.

504-13.6.1.3 Master meters are flowmeters which have been calibrated with standards traceable to the National Institute of Standards and Technologies (NIST). These meters are then placed in-line with the meter to be calibrated. Care must be taken to ensure that: a) the configuration the standard meters were calibrated under are repeated while calibrating other flowmeters, and b) the meter to be calibrated is placed in the same configuration as the standard meter. The standard flowmeters have historically been turbine flowmeters.

504-13.6.1.4 The flowmeter types listed below are covered by NAVSEA's Metrology and Calibration Program:

a. Turbine

b. Variable Area

c. Disc

d. Positive Displacement

e. Piston

504-13.6.1.5 These flowmeters are calibrated at a Type III calibration laboratory. The calibration cycle and NAVAIR 12-20MG series calibration procedures for these flowmeter types are listed in the **Metrology Requirements List** , NAVSEA OD45845, Section 3.

### 504-13.7 REFERENCE

504-3.7.1 Installation information for flowmeters is contained in American Society of Mechanical Engineers publication PTC 19.5; 4-1959: Flow Measurement, Part 5, Chapter 4 of **Power Test Codes Supplement** .

## SECTION 14.
## ACCELEROMETERS

### 504-14.1 VIBRATION BASICS

504-14.1.1 ACCELERATION, VELOCITY AND DISPLACEMENT RELATIONSHIPS. Vibration occurs when an object moves around a fixed position. This motion can consist of a single component occurring at one frequency or more typically several components occurring at different frequencies simultaneously. The foundation of diagnostic machinery vibration analysis is the breaking down of complex vibration into the individual component frequencies. These components correspond to events occurring in a machine. Vibration can be presented as displacement, velocity, or acceleration as a function of time. Refer to Figure 504-14-1. Considering vibration at a particular frequency, the displacement, velocity and acceleration of a vibrating object when plotted as a function of time are represented by sinusoidal curves. Their relationship to each other is as follows.

For a sine wave, the instantaneous displacement is:

$y = D\sin(\omega t)$

where:

$y$ = instantaneous displacement

$D$ = peak displacement

$\omega = 2\pi f$ ; $f$ = frequency in Hertz or 1/(period) t = time

Velocity of the vibrating object is the time rate of change of the displacement. The instantaneous velocity is:

$v = dy/dt = \omega D\cos(\omega t) = \omega D\sin(\omega t + 90°)$

The relationship between displacement and velocity descriptive magnitudes such as peak-to-peak, root-mean-squared (rms) and peak are:

velocity = $\omega$ x displacement

where: x = multiplication

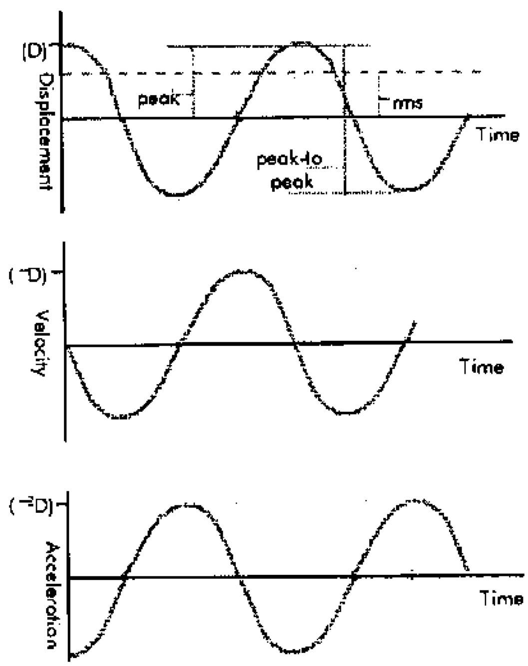



Figure 504-14-1. Acceration, Velocity and Displacement Relationships

The acceleration of the vibrating object is the time rate of change of the velocity. The instantaneous acceleration is:

$a = dv/dt = \omega^2\ 2D\sin(\omega t + 180°) = -\omega^2\ D\sin(\omega t)$

The relationship between displacement, velocity and acceleration descriptive magnitudes such as peak-to-peak, rms and peak are:

acceleration = $\omega$ x velocity = $\omega^2$ x displacement

504-14.1.2 LOGARITHMIC SCALE. Typically magnitudes of individual frequency components are presented in a logarithmic scale. A logarithmic amplitude scale provides the necessary range to allow vibration components to be plotted and easily analyzed. Consider vibration measured on a machine having linear rms velocity amplitudes of 0.000707 in/sec at 120 Hz and .707 in/sec at 60 Hz. When these values are plotted in a linear scale the event occurring at 120 Hz is too small to be adequately resolved. Refer to Figure 504-14-2. Their values in the logarithmic velocity-decibel (VdB) scale are 65 VdB at 120 Hz and 125 VdB at 60 Hz. When plotted in a logarithmic scale the 120 Hz component can easily be identified. Also, over time, proportional changes in values for each event is given equal magnitude in the logarithmic scale. For example, a doubling of vibration level is a six decibel increase regardless of the initial value. When trending magnitude changes of events occurring within a machine, an important part of machinery diagnostics, the logarithmic scale is the scale of choice.

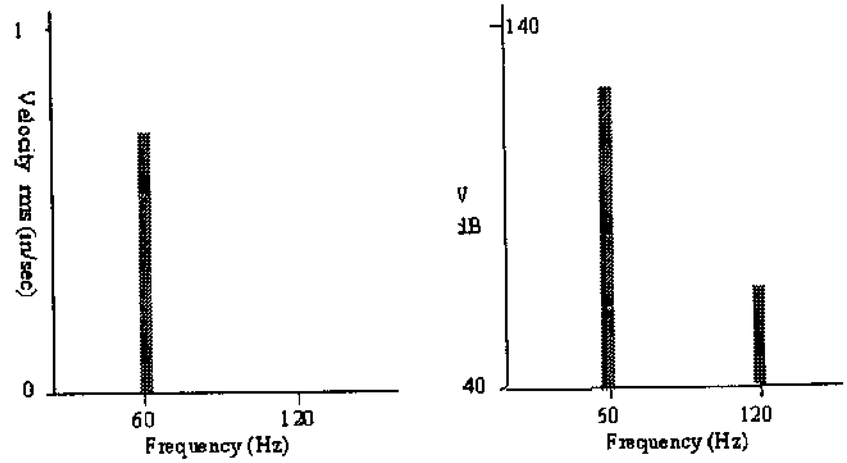



Figure 504-14-2. Logarithmic Representation Sample

504-14.1.3 DECIBELS. The logarithmic scales most often used are the velocity-decibel (VdB) and acceleration-decibel (AdB) scales. The decibel is the logarithmic ratio of one magnitude with respect to a magnitude amplitude. The definition of VdB is:

$VdB = 20Log_{10}$ {measured rms velocity (in/sec) ÷ 3.937EE-7}

The definition of AdB is:

$AdB = 20Log_{10}$ {measured rms acceleration (in/sec$^2$ ) ÷ 3.937EE-4}

## 504-14.2 DESIGN FUNDAMENTALS

504-14.2.1 PRINCIPLE OF OPERATION. Seismic accelerometers are the most common type of vibration sensor in use. Other types of vibration transducers measure velocity and displacement. Simple electronic circuits can be used to convert between displacement, velocity and acceleration in all three types of sensors. In practice, as in this chapter, the term accelerometer refers to seismic accelerometers. Accelerometers measure acceleration of an object with respect to a fixed point in free space as opposed to fixed-reference devices which measure motion between two points. The basic accelerometer can be represented by a mass connected to a base via a spring and damper in parallel. Refer to Figure 504–14–3. All accelerometers contain this fundamental mechanical sensing system. It can be shown that for frequencies below accelerometer resonance the change in length of the spring is equal to the acceleration of the vibrating object. To simplify the derivation of this relationship damping will be neglected. This is reasonable since most accelerometers have relatively low damping values. By summing forces the equation of motion for the mass is:

$m(a_{m-o} + a_{o}) + Ky_{m-o} = 0$

where:

m = Mass of inertial element

$a_{m-o}$ = Acceleration of the mass relative to the vibrating object

$a_{o}$ = Acceleration of the object relative to free space

k = Spring constant

$y_{m-o}$ = Displacement of mass relative to the vibrating object (change in length of the spring)

substituting (see 504-14.1.1)

$a_{m-o} = - \omega^2 (y_{m-o})$

yields:

$y_{m-o} / a_o = 1 / (\omega^2 - \omega_n^2)$

where:

$\omega_n$ = Natural frequency; $\sqrt{(k/m)}$

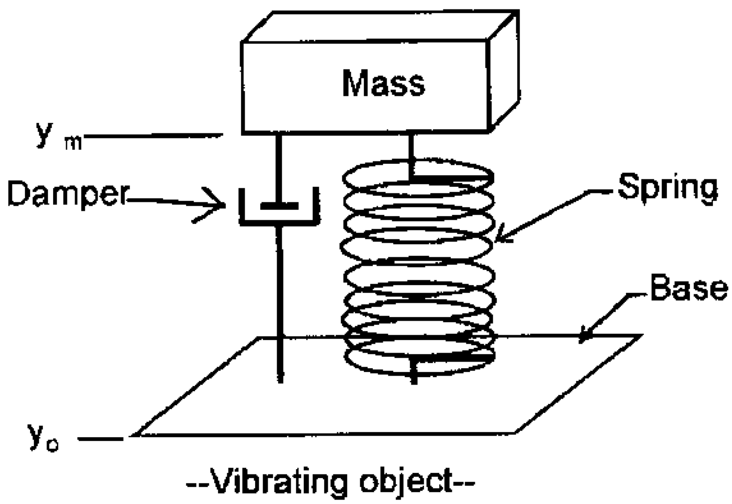



Figure 504-14-3. Vibrating Object

A plot of the magnitude of the ratio of relative displacement of the mass to the acceleration of the vibrating object $|(y_{m-o} / a_o)|$ is shown in Figure 504-14-4. At frequencies much lower than the natural frequency, the relative displacement of the mass is directly proportional to the acceleration of the vibrating object. Also, at the low frequencies, this ratio is independent of frequency.

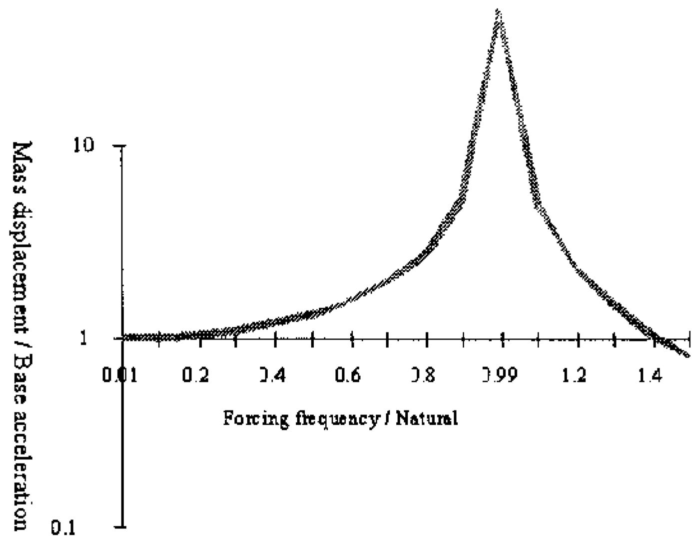



Figure 504-14-4. Plot of Frequency vs. Mass

### 504-14.3 TYPICAL ACCELEROMETER CONSTRUCTIONS

504-14.3.1 PIEZOELECTRIC ACCELEROMETERS. A piezoelectric material is one which develops an electrical charge when deformed. Some materials, like quartz, exhibit this property naturally. Other materials, like those grouped as artificially polarized ferroelectric ceramics, are manufactured. Piezoelectric accelerometers utilize a piezoelectric spring element that produces an electric charge proportional to the percent compression or expansion of the piezoelectric material. As shown in paragraph 504-14.2, the acceleration sensed by an accelerometer is proportional to the change in length of the spring element. Thus, the electrical charge produced is proportional to the sensed acceleration. Figure 504–14–5 depicts simple compression and shear configurations. While there are a variety of spring - mass configurations, the important thing to note is that the deformation of the piezoelectric spring element produces a charge that is proportional to the sensed acceleration.

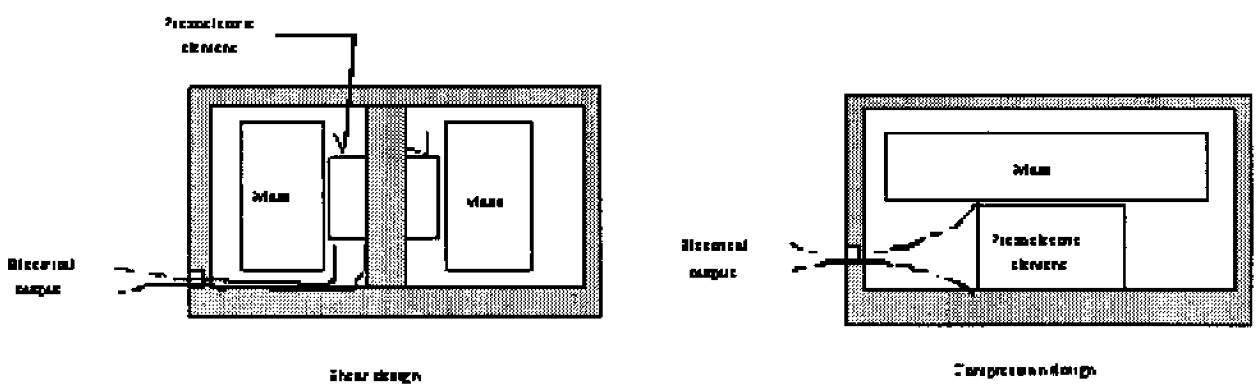


Figure 504-14-5. Simple Shear and Compression Designs

Piezoelectric accelerometers are not capable of measuring a dc response, such as the earth's gravity. The piezoelectric element will only produce a charge when acted on by a dynamic force. The actual low frequency response is determined by the RC (resistance-capacitance) circuit developed with the attached cable and which the charge leaks from piezoelectric amplifier. The RC circuit determines the rate at element, the slower the rate the lower the frequency response. See Figure 504–14–6 for the frequency response curve for a typical accelerometer. The high frequency limit is governed by the natural frequency of the mechanical sensing system.

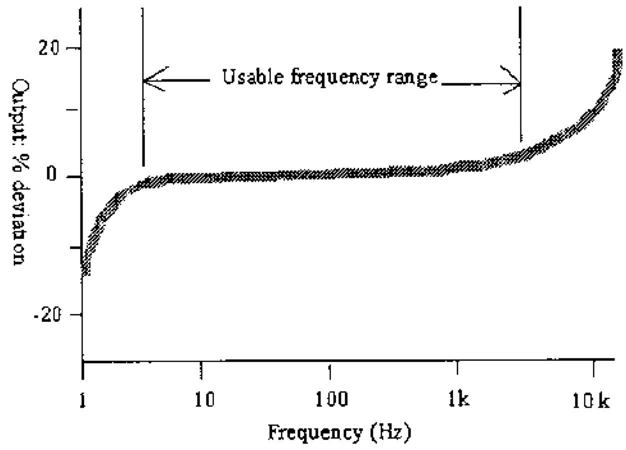



Figure 504-14-6. Typical Accelerometer Response Curve

504-14.3.2 HIGH IMPEDANCE PIEZOELECTRIC. In this type of accelerometer the highly resistive piezoelectric element is connected directly to the sensor's electrical output. Refer to Figure 504–14–5. To measure the small amount of charge developed across the piezoelectric element an isolation amplifier having an ultra-high input impedance must be employed. If connected directly to a conventional measuring device such as a voltmeter or oscilloscope the signal would quickly leak away. The most common isolation amplifier used is a charge amplifier which converts charge from the accelerometer to an amplified voltage output. The charge amplifier usually contains high and low pass filters, an adjustable gain and delectable integrators to convert to velocity or displacement. This type of configuration is very useful in high temperature applications where electronics must be at a cooler remote location.

504-14.3.3 LOW IMPENDANCE PIEZOELECTRIC. In this type of accelerometer, the piezoelectric element, where isolation and signal conditioning circuits are all internal, provides a low impedance voltage output proportional to sensed acceleration. See Figure 504–14–7. Power to operate the electronics along with the output signal are transmitted over the same wires. Typically in this configuration constant current is supplied to power internal electronics. The voltage output signal is riding on the dc bias voltage. This type of configuration offers high noise immunity making it suitable when long cable lengths are required.

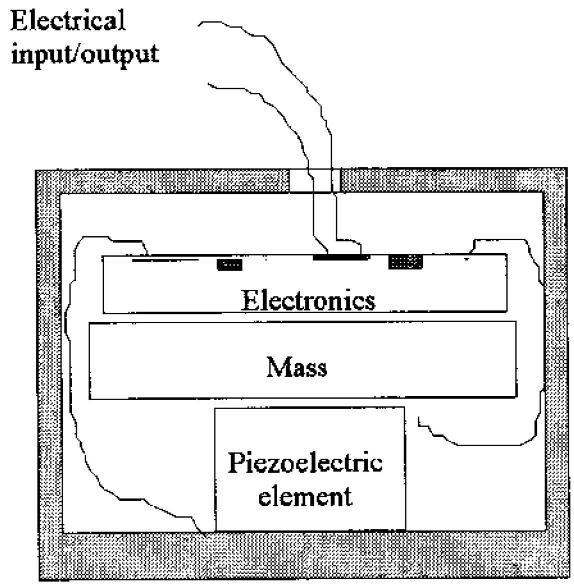



Figure 504-14-7. Low Impedance Piezoelectric Accelerometer

504-14.3.4 PIEZORESISTIVE ACCELEROMETERS. A piezoresistive material is one whose electrical resistance changes when deformed. Typically a semiconductor material, such as silicon, exhibits this property. The piezoresistive material is attached to the spring element of the accelerometer. As indicated in paragraph 504-14.2 the acceleration sensed by an accelerometer is proportional to the strain in the spring element. Thus, the change in electrical resistance of the piezoresistive element is proportional to the acceleration sensed. Figure 504–14–8 shows a simple cantilever-beam type accelerometer in a Wheatstone bridge arrangement. While there are a variety of spring-mass configurations, the important thing to note is the deformation of the spring element produces a change in resistance that is proportional to the sensed acceleration. Most accelerometers utilize four piezoresistive elements connected electrically to form a Wheatstone bridge. Some may use two sensing piezoresistive elements in a half - bridge arrangement. A regulated voltage excitation is applied to the bridge circuit via two input wires. The signal output voltage which varies with acceleration is obtained via two output wires. Some piezoresistive accelerometers have the entire mechanical sensing mechanism together with varying degrees of supporting electronics on a single silicon micro-structure. This type of technology is commonly referred as microelectricalmechanical systems (MEMS) technology. Unlike piezoelectric accelerometers, piezoresistive accelerometers are capable of measuring constant acceleration fields such as the earth's gravity. There is no lower frequency limit, the measuring capability extends down to 0 Hz. The high frequency limit is governed by the natural frequency of the mechanical sensing system.

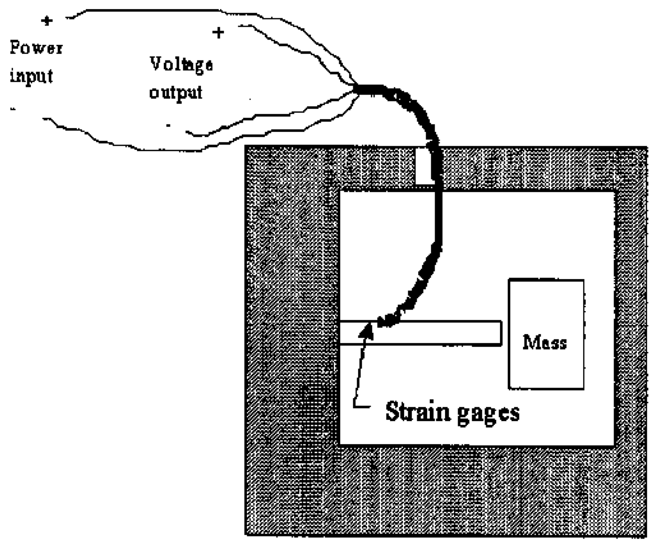



Figure 504-14-8. Simple Cantilever-beam Accelerometer

## 504-14.4 ACCELEROMETER CHARACTERISTICS

504-14.4.1 SENSITIVITY. The sensitivity of an accelerometer is defined as the electrical output per unit acceleration. Sensitivities are typically presented by manufacturers in the following manner:

Piezoelectric high impedance accelerometers; picoCoulomb per unit acceleration (example 50pC/g)

Piezoelectric low impedance accelerometers; Volts per unit acceleration (example 100 mV/g)

Piezoresistive accelerometers; Volts per unit acceleration at a particular excitation Voltage.

example: 10 mV/g @ 3 Vdc excitation

where: g = earth's gravity

= 386 inches/(second)$^2$

504-14.4.2 AMPLITUDE RANGE. The acceleration range of an accelerometer is defined as the amplitude range at which the sensitivity remains within specified limits (example .01g - 50g broadband, ±1% deviation).

504-14.4.3 FREQUENCY RESPONSE. The frequency response of an accelerometer is defined as the frequency range over which the sensitivity remains within specified limits (example 5 Hz - 10kHz, ± 10% deviation).

504-14.4.4 TRANSVERSE SENSITIVITY. Accelerometers are designed to measure along one axis, usually perpendicular to their mounting base. However, excitation along other axis may also be sensed. Transverse sensitivity is usually specified as the percent ratio of the maximum off-design axis sensitivity to the actual design axis sensitivity.

504-14.4.5 TEMPERATURE RESPONSE. The temperature response of an accelerometer is defined as the temperature range over which the sensitivity remains within specified limits (example -50°F to 250°F, ± 5% deviation).

### 504-14.5 ACCELEROMETER MOUNTING

504-14.5.1 SURFACE PREPARATION. The accelerometer mounting surface must be smooth, flat and free of foreign material such as paint. Machined mounting pads with threaded holes are usually welded or epoxied to the object to be measured. The accelerometer is attached to the pad via a stud. The accelerometer should be torqued to manufacturer's specifications. If torqued too low, the mounted resonant frequency will effect the accuracy of high frequency measurements. Torquing too high can damage the transducer. A drop of light oil between mating surfaces provides the necessary mechanical connection to measure high frequencies.

### 504-14.6 CALIBRATION

504-14.6.1 FIELD CALIBRATION. Accelerometers require periodic calibration. The most common calibration technique is the comparison method. In this method calibration is obtained by comparison with a reference standard accelerometer. The standard is charted at different frequencies and values by a Type II calibration laboratory. The two transducers, reference and unit under test, are mounted back-to-back and attached to a vibration generator which subjects the transducers to precisely the same motion. Amplitude and frequency can be varied to provide a comprehensive reference transfer calibration over the accelerometer's intended measurement range.

## SECTION 15.
## HYGROMETERS

### 504-15.1 ENGINEERING PRINCIPLES

504-15.1.1 INTENDED USE. Most naval vessels have systems to provide low pressure compressed dry air for a variety of essential mission functions. Some uses for low-pressure (normally 100 psig) air include flight deck warning systems, operation of portable pneumatic tools, engine room controls, or radar system pressurization. Some ships use high pressure (normally 3,000 psig or higher) air for oxygen and nitrogen plants, catapult systems or torpedo charging.

504-15.1.1.1 The performance of equipment using the compressed air is directly related to the air's water vapor content. Air exceeding the specified water vapor content will degrade system performance and cause frequent repair or premature overhaul or replacement of expensive system components. Electronic equipment, such as the radar, requires dry air to prevent arcing and to reduce internal corrosion and deterioration. Accurate measurements of the water vapor content in the compressed air system are essential to ensure the ship's service air does not exceed the specified water vapor content limits. A hygrometer is used to accurately monitor the water vapor content in air supplied by the compressed air system.

### 504-15.2 DEFINITIONS

504-15.2.1 HYGROMETER - an instrument used to measure the water vapor content in a gas. The term ″Frost Point/Dew Point (FP/DP) monitor″ and ″Moisture Monitor″ are used synonymously.

504-15.2.2 SATURATED GAS - a gas containing maximum water vapor content without forming condensation.

504-15.2.3 DEW POINT - the temperature at which the water vapor content in a gas condenses to form water droplets.

504-15.2.4 FROST POINT - the temperature as normally indicated in degrees Fahrenheit unless otherwise noted.

504-15.2.5 TEMPERATURE - the temperature as normally indicated in degrees Fahrenheit unless otherwise noted.

504-15.2.6 PPMw - the weight ratio of parts of water vapor per million parts of air.

504-15.2.7 PPMv - the volume ratio of parts of water vapor per million parts of air.

**504-15.3 SAFETY**

504-15.3.1 Always stop the sampling air flow to the hygrometer before connecting or disconnecting the sampling hose from the indicator.

504-15.3.2 Ensure that a relief valve is installed on the hygrometer.

**504-15.4 DESCRIPTION**

504-15.4.1 MOISTURE MEASUREMENT. The standard method for measuring the water vapor content in air is to measure the temperature at which condensation occurs on a chilled surface. The temperature at which the moisture begins to condense on a chilled surface is known as the dew point or frost point temperature.

504-15.4.1.1 Before the advent of technology, all measurements in PPMw and PPMv were converted from dew/frost point temperatures by charts and tables. With the development of electro-chemical sensors, the vapor pressure of air is measured to determine the moisture content. The vapor pressure can be related to the concentration of water in a gas by the equation:

$PPMv = P\ H_2O/P_T \times 10^6$ where

PPMv is the part per million by volumeP $H_2O$ is the vapor pressure of water measured by the hygrometer$P_T$ is the total system pressure

504-15.4.1.2 PPMw is related to PPMv by the equation PPMw = PPMv * 0.6222. The dew/frost point temperature, PPMw, and PPMv relationship was developed by three scientists (Laudsbaum, Dodds, Stutzman) and is known as the LDS chart seen in Figure 504–15–1.

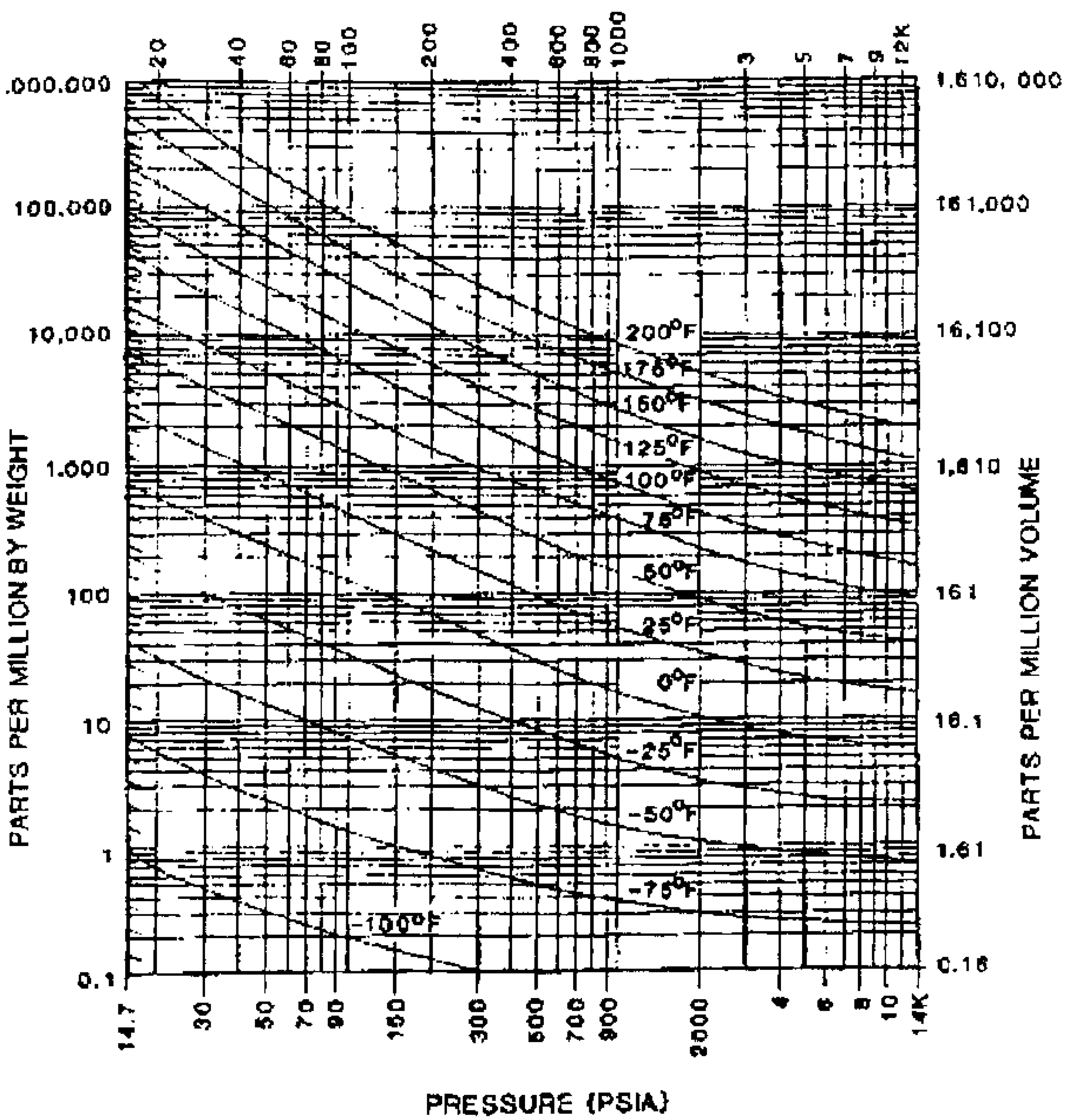



Figure 504-15-1. Laudsbaum, Doors and Stutzman Curve

504-15.4.2 SENSOR TYPES. The most common sensor being used is the chilled mirror surface. The method of using a chilled mirror surface is to cool down the surface of the mirror until moisture condenses upon the surface. Any type of surface will suffice, but a reflective surface permits easier detection of moisture formation on the surface. The temperature of the surface in which the moisture is detected is the dew point/frost point temperature.

504-15.4.2.1 Other types of sensors being used are composed of electro-chemical elements. Some of the electro-chemical sensor elements being used are Aluminum Oxide, Lithium Oxide, Phosphorous Pentoxide, and Silicon Oxide. The method of using the electro-chemical sensor elements is that the change in impedance of the electro-chemical elements is proportional to the amount of water molecules being absorbed from the gas. The amount of absorption of water molecules by the electro-chemical elements is proportional to the water vapor pressure. Hence, by knowing the change in impedance of the electro-chemical sensor element, the water vapor pressure is known and the moisture content in PPMv and PPMw can be calculated.

## 504-15.5 OPERATION

504-15.5.1 The operation of the hygrometer involves connecting a hose from the sampling port of the dry air system to the hygrometer inlet sampling port. The air being measured for moisture content flows into a sampling chamber where the sensor is located. The flow of air is controlled manually by inlet and outlet valves. When the flow of air through the hygrometer stabilizes and a drying time of 15-20 minutes has elapsed, the moisture measurement can be made either manually or automatically.

504-15.5.2 With the manual method, the condensation is detected by the operator while simultaneously measuring the temperature of the chilled surface. With the automatic method, the condensation is detected by electrical or optical techniques and a temperature, PPMv or PPMw value is displayed.

504-15.5.3 Some hygrometers have a shut off valve, flow valve, flow meter, pressure regulator and pressure indicator. The shut off valve is used to isolate the sample gas from the sampling chamber. When the shut off valve is closed, the sample air cannot flow into the sampling chamber. The flow valve is used to adjust the sample air flow rate into the hygrometer. The flow meter displays the flow rate and usually has a range of 0 to 10 standard cubic feet per hour (scfh). When taking a moisture measurement, the flow rate should be kept between 5 to 10 scfh. The pressure regulator is used to manually control the pressure of the sample air into the sampling chamber. The pressure indicator displays the pressure inside the sampling chamber.

## 504-15.6 CARE AND MAINTENANCE

504-15.6.1 With the exception of the manual operation of valves and making connections, the hygrometer operates without any moving parts, therefore, maintenance is kept to a minimum. Every six months valves, connectors and sampling hose should be checked for deterioration and replaced as required. Excessive water and contaminants should be vented from the sampling port of the dry air system prior to connecting to the hygrometer. In the event the sensor is exposed to excessive water or contaminants, the sensor should be dried or cleaned, and calibrated prior to use. The hygrometer should be stored in a dry environment at room temperature. Desiccant caps should be used on the hygrometer sampling inlet port to keep the sensor and sampling chamber as dry as possible.

## 504-15.7 CALIBRATION

504-15.7.1 Calibration of a hygrometer involves measuring air with known moisture content and comparing it with the hygrometer reading. Hygrometers are usually calibrated at an intermediate or higher laboratory. Hygrometers with electro-chemical sensors require an annual calibration due to the sensor's natural drift properties. Hygrometers using a chilled surface sensor should be calibrated every two to three years. In the event the sensor is exposed to excessive water or contaminants, the hygrometer must be recalibrated prior to further use. Refer to the **Metrology Requirements List** , NAVSEA OD45845 for the calibration interval for a specific model hygrometer.

# SECTION 16.
# SALINITY INDICATORS

## 504-16.1 ENGINEERING PRINCIPLES

504-16.1.1 CONDUCTIVITY AND SALINITY. Personnel and certain shipboard systems require a continuous supply of uncontaminated water. Water storage tanks and distillation systems require continuous monitoring to determine the dissolved and suspended contaminants in the water. In order to provide continuous monitoring, measurement of electrical conductivity by a salinity indicator is employed. This is valid since chloride (salt) ions constitute most of the conductive components in shipboard water systems. Therefore, a conductivity measurement is considered equivalent to a measurement of salinity. For this reason, the terms salinity and conductivity are often used interchangeably when referring to shipboard water systems. A true salinity measurement can only be obtained through a chemical analysis performed once each day to verify the salinity indicator. The manual analysis cannot be employed where continuous indication is required.

504-16.1.2 SALINITY MEASUREMENTS

504-16.1.2.1 Measurement Validity. The salinity indicator readout is valid when chloride ions are the only conductive components present. A salinity indicator actually detects all conductive contaminants in water such as hardness (calcium and magnesium), dissolved gasses (ammonia and carbon dioxide), and treatment chemicals (morpholine). In order to validate the indicator's readings, a chemical comparison test is performed daily on all water monitored by salinity indicators. The salinity indicator reading is acceptable if the results of the chloride chemical test are within +/- 0.02 equivalent parts per million (EPM) of the indicator reading. If the difference is out of this limit, then either the water contains additional conductive contaminants other than chloride or the salinity indicator is malfunctioning. **NSTM Chapter 220 Volume 2, Boiler Water/Feedwater - Test and Treatment** should be consulted for more information on chemical tests and water contaminants.

504-16.1.2.2 Temperature Compensation. The problem with using conductivity techniques to measure salinity is that conductivity changes with temperature. As the temperature of water increases, its electrical resistance decreases and its conductance increases. However, the salinity (salt concentration) remains the same. For this reason, the temperature compensation is required in conductivity measurements to provide accurate salinity measurements. Every conductivity indicator that uses a temperature compensator is designed at a base temperature (usually 25°C). At the base temperature, the conductivity reading does not need temperature compensation, and so the salinity reading is the same with or without temperature compensation. If a conductivity reading is not temperature compensated, the temperature at which the reading was made is usually provided.

## 504-16.2 DEFINITIONS.

Terms used in this section are defined as follows:

504-16.2.1 CELL CONSTANT. A constant value expressed in 1/cm or $cm^{-1}$ units. A low cell constant should be used to measure water with low conductivity values, and a high cell constant should be used to measure water with high conductivity values.

504-16.2.2 CELL TEST RESISTOR (CTR). One or more resistors in a single case (usually a decade resistor box) used to simulate a single fixed conductivity point.

504-16.2.3 CONDUCTIVITY. The ability of a 1-cm cube of liquid at a specified temperature to carry (conduct) an electrical current. The unit of conductivity is mho/cm, or siemens/cm. A more commonly used unit is the micromho/cm, or microsiemens/cm, which is one-millionth ($10^{-6}$) of a mho/cm.

504-16.2.4 DUMP VALVE. A solenoid type valve installed in a water line being monitored by a salinity indicator. The valve is energized (open) by an output from the salinity indicator when water being monitored has an acceptable conductivity. The valve is deenergized when the water being monitored exhibits an abnormal conductivity.

504-16.2.5 EQUIVALENTS-PER-MILLION (EPM). The chemical concentration of a solution expressed as a ratio of the chemical equivalent unit weight of a material dissolved in one-million parts by weight of solution.

504-16.2.6 GRAINS-PER-GALLON (GPG). A unit of chemical concentration of a solution expressed as a ratio of the parts by weight of material (grains of sea salt) dissolved in one gallon of solution.

504-16.2.7 HYDROSTATIC (TEST) PRESSURE. The pressure introduced to the equipment during testing to ensure the equipment can withstand 150% of the working pressure. The terms hydrostatic pressure and test pressure have the same meaning and are interchangeable terms.

504-16.2.8 ISOLATION VALVE. A valve located along the system piping of the salinity cell which, when closed, allows the cell to be isolated from the water flow for maintenance.

504-16.2.9 MODULE. An interchangeable component in a ″modular″ salinity panel. The module is usually secured to the front of the panel by thumbscrews. It electrically interfaces with the printed circuit boards of the panel's interior by multi-pinned plug-in connectors. Typical salinity panel modules are the salinity channel module (also known as: SCM, salinity control module, or salinity alarm module), the meter module, the dump module, the power module, and the bell module.

504-16.2.10 PARTS-PER-MILLION (PPM). A unit of chemical concentration of a solution expressed as a ratio of the parts by weight of material dissolved in one-million parts by weight of solution.

504-16.2.11 SALINITY. A measurement of the amount of dissolved salt (chloride) ions in a unit of water, often measured as a ratio of the parts of chloride ions to the quantity of water. Commonly used salinity units are PPM, EPM, or GPG.

504-16.2.12 SALINITY CELL. A probe containing electrodes which pass an electrical current through a sample of water to measure the water's ability to conduct the electric current. A salinity cell is also known as a salinity sensor and a salinity probe, as well as a conductivity cell, sensor, and probe.

504-16.2.13 SALINITY PANEL. A unit, which transmits and receives the signals to/from the salinity cells. The panel provides indication on a meter display, provides audible and visual displays of preset normal, alarm, and dump conditions, and it provides signals to dump valves and repeater panels. A salinity panel is also known as a salinity console or indicator. A main panel is known as a basic panel and a remote panel is known as a repeater panel.

504-16.2.14 SALINITY VALVE. A valve assembly used to insert, remove, and hold a salinity cell in the water flow stream of a ship's pipe.

504-16.2.15 TEMPERATURE COMPENSATOR. An electrical network of thermistors designed into a salinity cell to accommodate the variations in water conductivity resulting from changes in water temperature. The compensator is designed at a base temperature (usually 25°C) which is the only temperature at which the conductivity measurement needs no compensation.

504-16.2.16 WORKING PRESSURE. The pressure introduced to the equipment during normal operating conditions.

## 504-16.3 SAFETY

504-16.3.1 GENERAL. Due to the design and environment of salinity systems, there are several safety considerations.

504-16.3.2 ELECTRICAL HAZARD. All permanently installed salinity panels are energized with 115 Volts and high current which is dangerous to the operator's life. Some maintenance procedures require the operator to open the panel and make adjustments or connections in the panel interior while the panel is energized. Some older salinity cells (before MIL-S-15103 Revision E) operate with a high voltage and current which make them dangerous to handle when energized and removed from their holding valve. The following safety precautions should be taken when working with this type of energized equipment:

1. Do not work alone.
2. Do not wear metal articles or loose clothing.
3. Insulate deck or standing surface from ground by covering it with dry insulating material.
4. Wear rubber electric safety gloves.
5. Wear face shield.
6. If practical, use one hand to do work.
7. When deenergizing the equipment, ensure all tag out procedures are performed in accordance with current shipboard instructions.
8. Consider all electrical leads to be energized until positively proven they are deenergized.

504-16.3.3 MECHANICAL HAZARD. The high pressure and temperature conditions at the cell and valve assembly create a mechanical hazard to the operator. The following two paragraphs describe the hazards from these two conditions and the necessary safety precautions.

504-16.3.4 MECHANICAL HAZARD FROM PRESSURE. The typical operating pressures for a salinity cell installed in a condensate or distilling plant range from 14.7 psi (30 in. Hg) to 250 psi. The operating pressure for a salinity cell in the reboiler system can rise to 800 psi. The salinity valve holds the cell in the system piping by means of threads or a mechanical stop. When the cell is being removed from the valve, it can become a projectile while exposed to the system pressure. Many cells can suddenly project out several inches while the threads are being loosened or the mechanical stop is being removed. The following safety precautions should be taken when working with a cell under these conditions:

1. Do not stand directly behind cell while loosening.
2. Do not loosen threads beyond indicated number of turns during removal stages.
3. If applicable, close isolation valves prior to removal of cells.

504-16.3.5 MECHANICAL HAZARD FROM TEMPERATURE. The typical operating temperatures for a salinity cell installed in a condensate or distilling plant range from 40°F to 300°F. The operating temperature for a reboiler salinity cell can reach 500°F. The high temperature system water often leaks out through the threads or the mechanical stop between the cell and the salinity valve. Many cells also have a weep hole to indicate when system pressure is present. Hot system water can spray on the operator from the weep hole. The cell and valve are also very hot and can burn the operator. The following safety precautions should be taken when working with a cell under these conditions:

1. Wear gloves to protect hands from hot surfaces.
2. If possible, isolate cell from system water and allow time to cool prior to removal of cell.
3. Examine weep hole to ensure system pressure is reduced. Water or steam leakage from weep hole indicates a faulty valve when closed.
4. Ensure all tag out procedures are performed in accordance with current shipboard instructions.

## 504-16.4 DESCRIPTION

504-16.4.1 CLASSIFICATION OF SALINITY SYSTEM TYPES. All salinity indicators on naval vessels can be classified into the following four category types:

| | |
|---|---|
| Category 1 Equipment. | Newer systems designed, tested, and qualified in accordance with MIL-S-15103 Revision E or later. |
| Category 2 Equipment. | Older systems designed, tested, and qualified in accordance with MIL-S-15103 Revision D or earlier. |
| Category 3 Equipment. | Systems designed and tested using MIL-S-15103 as a guide, but only First Article contract approved. |
| Category 4 Equipment. | Commercial systems. |

**NOTE**

The equipment is assigned to these categories only for convenience to quickly identify the type of equipment being discussed within this section. The categories do not hold any meaning apart from this section.

504-16.4.1.1 Category 1 vs. Category 2 Systems. Category 2 equipment provided the Navy with numerous varieties, model types, and configurations of the different components comprising a salinity system. In order to resolve this problem, category 1 systems were developed to simplify the variety of components. Since 1983, ships have been receiving SHIPALTS to replace the category 2 systems with category 1 systems.

504-16.4.1.2 Category 3 Systems. Although category 1 equipment was developed to apply to all ship systems, new applications arise that require slight modifications. Category 3 systems are developed to suit special applications where category 1 equipment would not be appropriate. Two examples are the Eaton digital salinity indicator for use on nuclear and auxiliary ships (SSN 21, CVN 68-75, AS 31-41, and AD 37-44), and the Marine Electric Hydrazine salinity indicator (IC/SB-7-B-0D-01000M-3 panel and the IC/SB-2-U2 cell) for use on Chelant boiler feedwater treatment systems.

504-16.4.1.3 Category 4 Systems. Category 4 systems are known to be smaller, less rugged, less expensive, non-modular indicators. These systems are often referred to as conductivity indicators. Many of the category 4 indicators are provided as a part of the larger water system. Other category 4 indicators are used in a laboratory environment or are portable handheld systems. These indicators are different from the systems in the three other categories in that they only monitor one cell, rather than the ″multi-channel″ indicators that can monitor several cells at various locations. The category 4 cells that are portable or used on a laboratory benchtop are dip-type cells. They are for single point conductivity measurements of water samples in a beaker, rather than being installed in ship's piping and providing continuous conductivity measurements.

504-16.4.2 SALINITY SYSTEM COMPONENTS. Salinity indicating equipment consists of an indicating panel, cells, valve assemblies, dump valves, repeater panels, remote meters, and remote alarms. Since there is such a wide variety of the types and functions of these components, a salinity system must be configured with its proper components in order to operate properly. Figure 504–16–1 shows a layout of the components, how they are interconnected, and how the signals flow between components. The various components and types of salinity indicating equipment covered by this document are described below.

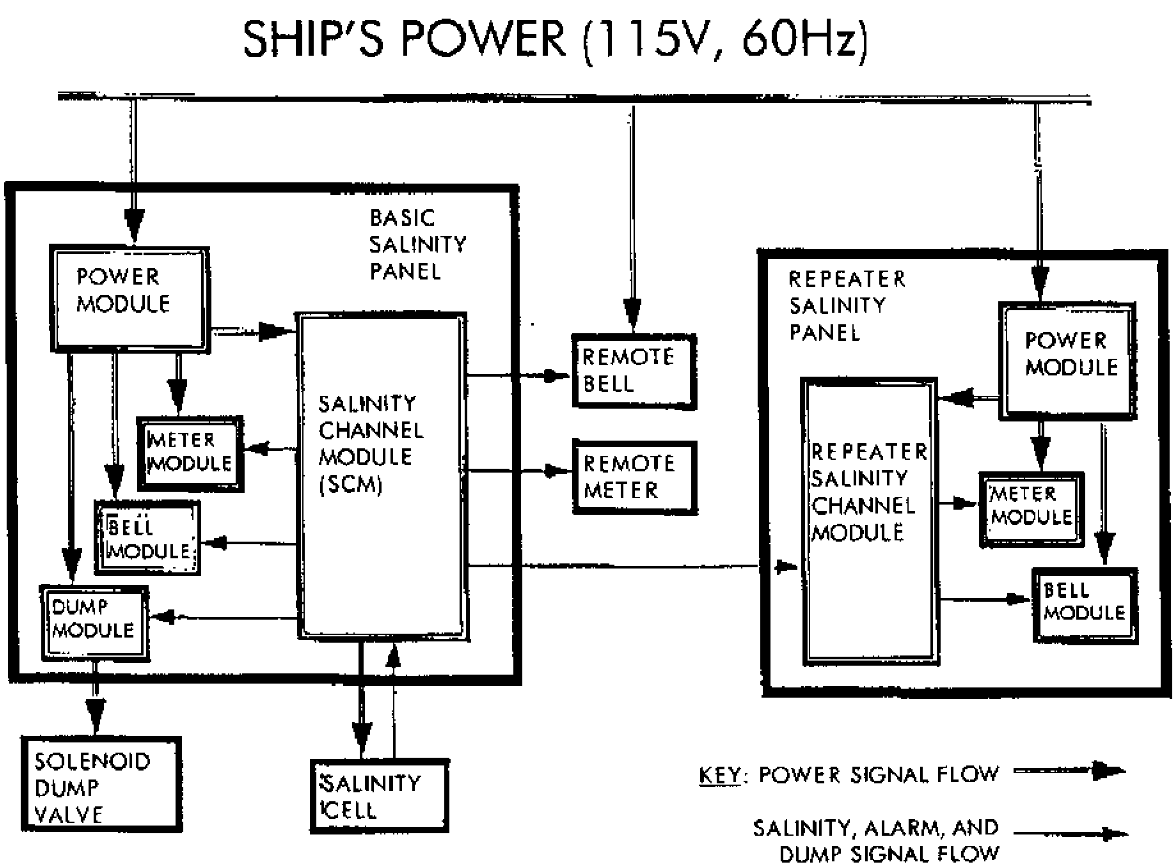



Figure 504-16-1. Salinity Indicating Equipment Layout

504-16.4.2.1 Salinity Panel. The basic salinity panel is the central component of a salinity indicating system. It receives and distributes the system's power and salinity signals to most of the other components. The exception is the power to an optional repeater panel and to an optional remote alarm, which receive their own power directly from the ship. Pertinent information about the salinity system (such as operating instructions and a sensor directory) are provided on the front face of the panel. A permanently installed panel can monitor several cells at various piping locations. It does this using a channel selector switch and separate cell channel circuits. This type of panel is called a ″multi-channel″ panel. If the panel components are located on plug-in type modules, the panel is called a ″modular″ panel. A salinity indicating panel contains the following components:

a. Meter

b. Alarm lamp(s)

c. Audible alarm (bell)

d. Dump lamp(s)

e. Sensor simulator

f. Channel selector switch

g. Alarm set point potentiometer

h. Fuses

i. Power lamp

504-16.4.2.2 Modular Salinity Panel. A modular panel contains these items on its power module, salinity channel module(s), meter module, dump module, and bell module. Each module and its functions are described below:

**NOTE**

The modules and components listed below are described as generally as possible. When the names and locations of the components are diverse (but relatively insignificant), category 1 systems are described for simplicity and clarity. Some systems may not have the components listed, and some may have additional components. The purpose of the descriptions is to identify the **function** of the components.

504-16.4.2.2.1 Power Module. Directly receives 115 V, 60 Hz power from the ship and passes it through fuses. The power module develops DC and square wave operating voltages and distributes them to the other panel components and to the cell. On category 1 and 2 panels a green indicator light illuminates when power is received by the panel.

504-16.4.2.2.2 Salinity Channel Module (SCM). A panel is equipped with one salinity channel module (SCM) corresponding to each salinity cell being monitored. The SCM sends an electric current to a cell, then receives the salinity signal from the cell. This signal is sent to the panel meter for indication. If the signal is above the preset alarm set point, a signal is sent to the bell module and to the dump module. If a repeater panel, a remote meter, or a remote alarm is connected to the panel, the SCM sends the associated signals to those components.

504-16.4.2.2.2.1 SCM Salinity Range. The SCM is designed to correspond with a specified meter scale. It is critical that the salinity range of each SCM installed in a panel match the salinity range of the installed meter.

504-16.4.2.2.2.2 Alarm Level Control Potentiometer. The SCM contains the alarm level control potentiometer. This potentiometer is usually discreetly located on the SCM (or on the panel interior for some non-modular panels) to prevent inadvertent adjustment of this important setting. The alarm level control potentiometer adjusts the level of the preset alarm point when used with the sensor simulator. For the category 3 Eaton digital panel, the alarm level is set with microprocessor based dip switches. This panel also has a low salinity loss-of-detector set point, which indicates a failure at the cell when reading below a minimum salinity set point.

504-16.4.2.2.2.3 Sensor Simulator. The sensor simulator is used to set the alarm set point, to check/test the alarm set point level, and to ensure smooth movement of the meter needle. The sensor simulator consists of a simulator function switch and a simulator potentiometer. The simulator function switch is usually located on the SCM, while the simulator potentiometer can be located on each SCM or on the meter module. When the simulator switch is held in the ″SIMULATE″ position, the meter displays the level of the simulator potentiometer rather than the normal salinity cell display.

504-16.4.2.2.2.4 Bell Cutout Switch and Alarm Lamp Logic. The SCM also contains an alarm lamp and a bell cutout switch that silences the audible alarm. The alarm lamp (usually red) has a logic (off, flashing, on steady) to indicate the salinity condition and the position of the bell cutout switch. The alarm lamp for category 1 systems and some other systems has the following logic:

1. With the bell cutout switch in NORMAL position,
   a in a Normal salinity condition, the alarm lamp is **off** .
   b in an Alarm salinity condition, the alarm lamp is **flashing** .

2. With the bell cutout switch in CUTOUT position,
   a in an Alarm salinity condition, the alarm lamp is **on steady** .
   b in a Normal salinity condition, the alarm lamp is **flashing** .

504-16.4.2.2.3 Meter Module. The meter module provides the indication of the salinity cell selected on the channel selector switch. The channel selector switch is a rotary knob numbered with the maximum quantity of cells that the panel can monitor.

504-16.4.2.2.3.1 Meter Scale. The meter on the meter module is available in several salinity ranges and different units (0-1.5 EPM, 0-10 PPM, 0-50 micromhos/cm, etc.). Most of the meters on salinity panels are analog. Newer technology is replacing the analog meter with a digital meter. The category 3 Eaton digital panel is an example, along with some of the newer category 4 commercial conductivity indicators. The range and units of the meter scale must correspond with the range and units of the SCM. The meter scale is often semilog and circular. It is usually designed so that typical normal indications that are below the alarm set point are located at the lower left end of the scale. This area of a semilog scale is more spread out, which improves the accuracy and readability of the indication.

504-16.4.2.2.3.2 Test Button. The meter module also contains a meter test button for performing a quick check of the meter operation. When the button is depressed, the needle should point to a test mark on the meter face.

504-16.4.2.2.4 Dump Module. When the SCM receives an alarm signal from the cell, it sends a signal to the dump module. The signal trips a relay in the dump module, removing power from the solenoid dump valve associated with the cell sensing the alarm condition. Loss of power at the solenoid dump valve causes the valve to dump the water to the bilge. The dump module has dump indication lamps (usually yellow). The dump lamp is on steady for normal conditions and flashes when the associated dump valve is dumping. A single dump module can monitor several dump valves. For category 1 systems, a dump module can monitor up to three dump valves associated with three cells. The panel can be configured to associate the desired cell with the desired dump valve.

**NOTE**

To ensure the correct dump valve is being monitored by its corresponding cell, the operator must take care in properly wiring of the dump module circuit (the proper cell is connected to the proper SCM, which is connected to the proper dump module circuit, which is connected to the proper dump valve). Improper wiring will cause contaminated water to pass at one dump valve location, and good water to be dumped at another dump valve location.

504-16.4.2.2.5 Bell Module. The bell module contains a bell that provides an audible alarm. The bell rings when it receives an alarm signal from any SCM on the panel. The bell stops ringing when the alarm is removed or when the bell cutout switch is used.

504-16.4.2.3 Salinity Cells. There are many types of salinity cells which differ in electrical design, shape/size, and material. These different features of a cell are described in paragraphs 504-16.4.2.3.1 through 504-16.4.2.3.7.1.

504-16.4.2.3.1 Cell Electrical Design. When an electric current is sent to a salinity cell from the panel, its electrical design determines how the current is going to be affected by the environmental parameters (conductivity and temperature) which it is to measure. The electrical design of a cell is defined by its cell constant and its temperature compensator. The design of the cell constant determines how the water conductivity is to be converted to a resistance measurement. The design of the temperature compensator determines how the affect of temperature on the water conductivity is to be converted to a resistance measurement. These two resistance components are then sent back to the panel as a single signal to be displayed as a salinity measurement.

504-16.4.2.3.2 Sensor Constant. A salinity cell has outer and inner electrodes, which are two parallel conductive surfaces (usually made of platinum or palladium) facing each other. The closer and larger the surfaces of the electrodes are, the smaller the sensor constant. The cell constant must be designed to provide sufficient distance between the electrodes to allow for cell cleaning. The sensor constant is designed to match a specific salinity range. Generally, low sensor constants should be used for low salinity ranges and high sensor constants should be used for high salinity ranges. References such as ASTM D 1125 provide recommendations on the cell constant that should be used for a salinity range.

504-16.4.2.3.3 Temperature Compensator. The temperature compensator is also designed for a specific salinity range for the operating temperatures of the water system in which the cell is used. A thermistor network is designed to counter-balance the phenomenon that as the water temperature increases so does the water conductivity. The thermistor network is usually located very close to the inner electrode of the cell to respond to the fluid temperature. Some commercial cells (category 4) are designed without a temperature compensator. They must be used with a temperature compensator probe also wired to the indicator to provide correct readings.

504-16.4.2.3.4 Cell Shape/Size. If a cell is inserted with the assistance of a salinity valve, it will have a different shape from a cell installed by screwing into the threads of a piping tee or a cell holder.

504-16.4.2.3.4.1 Most cells are designed to have the fluid pass by the electrodes through radial holes between the inner and outer electrodes. These cells have parallel circular plate electrodes, or concentric electrodes. Other cells have the fluid flow through the cell, entering a hole at one end of the cell, and exiting another hole at the other end of the cell. These cells have their electrodes located within the cell in the path of fluid flow.

504-16.4.2.3.4.2 The length of the cell is critical. It enables the cell electrodes to be in the proper location in the water flow for making an accurate measurement of the water. Improper length can cause damage to the cell electrodes if they bottom out against the interior wall of the system piping. The cell can also be crushed if it is not the proper length and cannot be fully extracted prior to closing the salinity valve.

504-16.4.2.3.5 Cell Material. The material of the salinity cell is either brass or corrosion resistance stainless steel (CRES). Commercial cells (category 4) can be made of any material including glass and plastic, especially if they are the dip type. Brass cells are designed to be used with brass/bronze valves and piping. CRES cells are designed to be used with CRES valves and piping.

504-16.4.2.3.6 Cell Interchangeability. Since there are many different types of cells, it is essential to configure the proper cells with the exact panels with which they are designed to be used. If improper cells are connected to a panel, they will produce erroneous and misleading indications. There are, however, some cells that are designed to be interchangeable. Category 1 cells made by different manufacturers are interchangeable only if they share the identical model number. (For example, the Marine Electric IC/SB-1 is interchangeable with the Beckman IC/SB-1.) There are several category 2 cells that are also interchangeable, but only those that are specially designed to replace another manufacturer's cell. These cells have different model numbers from the cells they are replacing. (For example, the Beckman CEL-262 is interchangeable with the Marine Electric IC/CN8-M2).

504-16.4.2.3.7 Cell Test Resistor (CTR). A cell test resistor is a component designed for a specific salinity cell to simulate a fixed conductivity reading. It is used in the maintenance of the cell to check the wiring of the cell and the wiring between the cell and the panel. When the cell is deenergized, removed from its piping system, and brought to room temperature, the CTR is attached to the cell. Some types are clipped on the cell between the inner and outer electrodes. Other types are screwed on the cell in place of the outer electrode. Once the CTR is attached to the cell, the cell is energized and the simulated indication is read at the meter. The reading is compared with the acceptable range marked on the CTR.

504-16.4.2.3.7.1 Only category 2 systems use CTRs. They were not designed to be used with category 1 systems due to their limited function and the potential harm to the cell. Their function is limited because they do not check the accuracy of the cell (ignores cell constant accuracy). They are potentially harmful to the cell during installation, having direct contact with the sensitive platinum electrode surface, and requiring removal of the outer electrode.

504-16.4.2.4 Salinity Valve Assembly. A salinity valve assembly consists of the valve and its end adapters. Category 1 valve assemblies use a brazed or welded adapter to interface between the valve body and the system piping, and a threaded adapter to interface between the valve body and the cell. As stated in the paragraph 504-16.4.2.3.5, a salinity valve assembly should match the material of the cell it holds.

504-16.4.2.4.1 There are several different types of salinity valve designs. Two commonly used types are the gate valve and the coaxial valve. All category 1 valves are gate valves. Category 1 gate valves must conform to the design specifications required by NAVSEA Drawings 803-5164166 for a bronze valve assembly, and 803-5164167 for a CRES valve assembly.

504-16.4.2.4.2 The function of a salinity valve assembly is to hold the sensor within the water flow stream of the system piping. The valve assembly also allows for insertion and removal of the cell in a pressurized working system without discharge of system fluid.

504-16.4.2.4.3 Specific adapters are usually required for installing a salinity valve into a ship's pipe. Regardless of the valve type, the distance of the valve from the ship's pipe is critical. The adapter used between the valve and the pipe allows the cell electrodes to extend into the water flow stream.

**NOTE**

Some salinity cells are held in system piping using a tee or a sensor holder. These components are welded or brazed into the system piping and allow the cell to be threaded directly into the system fluid without a salinity valve. For these applications, isolation valves are used to insert and remove a cell in a pressurized system.

504-16.4.2.5 Dump Valve. Solenoid dump valves are located closely downstream from the corresponding salinity cell monitoring the water of the pipe on which it is mounted. The energized solenoid keeps the valve open allowing water to pass while normal water conditions are detected. When an alarm condition is detected, a relay in the panel trips, removing power from the solenoid. The deenergized solenoid causes the dump valve to dump, diverting contaminated water to waste (the bilge). When the alarm has been cleared and the salinity indication returns to an acceptable level, the dump valve must be manually reset. If a simulated salinity indication is being input and dumping of the solenoid dump valve is not desired, the dumped valve must be securely pinned to prevent automatic dumping.

504-16.4.2.6 Repeater Panel. A repeater panel is an optional remote monitoring station duplicating meter and alarm signals from the active salinity channels of the basic panel. There are no active modules on the repeater panel. The channel modules on the repeater panel are called repeater channel modules. They only have an alarm indicator lamp and a bell cutout switch. The meter module on the repeater panel has a channel selector switch to observe the duplicated meter indication of the desired channel.

504-16.4.2.7 Remote Meter/Remote Alarm. Individual remote meters and remote alarms (bells) may be connected to a basic panel in addition to, or in place of, the repeater panel. These remote indicators are not part of any salinity panel, but may be installed in another indicating control panel as desired by the user. The remote meter must be calibrated by the user as designated by the manufacturer of the basic panel.

504-16.4.3 WATER SYSTEMS. Salinity systems are installed on the following water systems on naval vessels: Distilling/Evaporator Plants (1SB Circuit), Propulsion Condensate Plants (2SB Circuit), Electronic Cooling Water System (4SB Circuit), Reboiler Feedwater System (5SB Circuit), and Nuclear Reactor Make-up Water (6SB/12SB Circuit).

### 504-16.5 OPERATION

504-16.5.1 GENERAL. A description of how the individual components of a salinity system operate has been provided above in paragraph 504-16.4. The following paragraphs describe how these components work together as a system.

**NOTE**

The following description of the system operation refers to Figure 504–16–1. It is a simplified general description of how the signals are sent between the system components. It may overlook more specific details of actual systems, but it demonstrates the essential signal flow process.

504-16.5.2 SYSTEM OPERATION. The power module of the basic panel is energized with 115 V at 60 Hz from ship's power. The power goes through the fuses of the power module and then is sent to the salinity channel module (SCM). The SCM sends power to the cell and then receives a salinity signal from the cell. The SCM sends the salinity signal to the meter module. The meter needle is deflected and the salinity level is displayed.

504-16.5.2.1 If the salinity level is below the alarm set point (good water), the following occurs:

1. The alarm lamp on the SCM remains off.
2. The bell remains silent.
3. Power going from the SCM to the dump module continues to be sent from the dump module to the solenoid dump valve. This keeps the solenoid energized, and the good water passes and is not dumped.
4. The dump lamp on the dump module remains on steady, indicating no dumping.

504-16.5.2.2 If the salinity level is above the alarm set point (contaminated water), the following occurs:

1. The alarm lamp on the SCM flashes, indicating an alarm condition.
2. Power is sent from the SCM to the bell module, and the bell rings.
3. Power to the solenoid dump valve is cut off and is no longer sent from the dump module. This deenergizes the solenoid and the valve dumps the contaminated water.
4. The dump lamp on the dump module flashes, indicating water is being dumped.

504-16.5.2.3 If the bell cutout switch is switched from NORMAL to CUTOUT while the salinity level is above the alarm set point (contaminated water), the following occurs:

1. The alarm lamp on the SCM flashes, indicating an alarm condition.
   a an alarm condition, and
   b the bell cutout switch is in CUTOUT position.

2. Power from the SCM to the bell module is cut off and the bell is silenced.

3. Power to the solenoid dump valve remains cut off. The dump valve continues dumping.

4. The dump lamp on the dump module continues to flash, indicating water is still being dumped.

504-16.5.2.4 When the salinity level is restored to a level below the alarm set point (good water) and the bell cutout switch is still in the CUTOUT position, the following occurs:

1. The alarm lamp on the SCM is flashing, not indicating an alarm condition, but indicating the bell cutout switch is still in CUTOUT position.

2. The bell remains silent.

3. Power is restored to the solenoid dump valve from the dump module. However, since the valve was tripped, it will continue to dump water until it is manually reset. When the valve is reset, the energized solenoid keeps it open and the good water passes and is not dumped.

4. The dump lamp on the dump module will continue to flash until the dump valve is manually reset. When the dump valve is reset, the dump lamp will be on steady, indicating no dumping.

504-16.5.2.5 When the final step is taken to switch the bell cutout switch from CUTOUT back to NORMAL, the same conditions exist as listed in occurrences 1 through 4 of the preceding paragraph, except the alarm lamp goes from flashing to off.

504-16.5.2.6 If a repeater panel is connected to the salinity system, the salinity signal from the SCM of the basic panel is sent to the SCM of the repeater panel. The repeater panel is also energized with 115 V at 60Hz from ship's power. The power goes through the fuses of the repeater power module, and then is sent to the repeater SCM. The salinity signal is sent from the repeater SCM to the meter module, where the salinity level is displayed on the meter. Since the alarm set point is determined at the SCM of the basic panel, an alarm condition is also determined at the basic panel, not the repeater panel. The alarm conditions will be the same as determined at the basic panel. However, the bell cutout controls of the repeater panel can be operated independent of the bell cutout controls of the basic panel. The function of the controls and the logic of the alarm lamp is the same as the basic panel.

504-16.5.2.7 If a remote meter is connected to a salinity system, it must be calibrated as required by the manufacturer of the salinity system. The salinity signal is sent from the SCM of the basic panel to the remote meter. The salinity level is displayed on the remote meter.

504-16.5.2.8 If a remote bell is connected to the salinity system, it must be connected to ship's power. The connection to the basic panel acts as a switch (relay) in a circuit connecting the remote bell to ship's power. If the salinity signal at the SCM is below the alarm set point (good water) the SCM relay keeps an open circuit and prevents the direct ship's power from energizing the remote bell. If the salinity signal is above the alarm set point (contaminated water), the SCM relay closes the circuit and allows the remote bell to receive 115 V at 60 Hz from ship's power. This causes the remote bell to ring. The bell cutout controls do not affect the remote bell. When the alarm condition is cleared, the SCM relay opens the circuit again. The ship's power is cut off from the remote bell and the bell is silent.

504-16.5.3 LOCATION SELECTION

504-16.5.3.1 Panel Location. A salinity indicating panel should be located in a space where the visible and audible indications can be detected and the controls can be easily accessed. Adequate space should also be provided so that the modules can be removed, the panel door can be opened, and the panel interior can be accessed. The panel should be properly mounted to the bulkhead and care should be taken in installing the external cables and making the proper wiring connections.

504-16.5.3.2 Cell Location. A salinity cell should be located in a space where it can be easily installed and removed in the system piping. A piping system location should be selected so that the cell electrodes are fully immersed in the fluid stream at all times. Low points in the system piping where sediment may collect should be avoided. Also, a cell should be installed so that its electrode end is pointed downward to prevent sediment from collecting around the electrodes. A cell, along with its cable plug and receptacle, should be located out of the bilge so it is not flooded by water or oil.

504-16.5.3.3 Valve Location. When a salinity valve is being installed in ship's piping, the permanent location of the valve body is critical. It must be located at a required distance from the ship's pipe to allow a fully inserted cell's electrodes to be in the water flow of the pipe. There should be no extra adapters, bosses, or extenders between the valve and the pipe. The NAVSEA standard valve assembly drawings, 803-5164166 and 803-5164167, specify a required distance for installation of category 1 type valves. Ample space should also be provided to allow for operation of the salinity valves, especially older valves that may have rising stems.

## 504-16.6 LOCATION SELECTION

504-16.6.1 EQUIPMENT CARE. Improper handling, operation, or maintenance of salinity indicating equipment can damage it and/or the systems on which it is used. If the required care is not taken, the following damage to the equipment can result:

1. If the cell cable is not coiled up and rotated with the cell as the cell is being installed or removed, the cable and the internal wires can become twisted and broken.
2. If the cell is not fully withdrawn from its salinity valve before the valve is closed, the cell can be crushed.
3. If the cell is not adequately cleaned and the electrodes have any corrosion, scales, or other coating, the cell will not provide accurate readings.
4. If the cell electrodes are improperly handled, are scratched or dented in any way, the cell will not provide accurate readings.
5. If the salinity equipment components are improperly configured with the wrong components (improper salinity range, improper size, etc.), the equipment will not provide accurate readings.
6. If the material of the cells and valves are mismatched, the threads between the cells and valves can be damaged.
7. If the cell and dump circuits are improperly wired, contaminated water can be passed and good quality water can be dumped. (Refer to the note under the dump module description paragraph.)
8. The greatest damage to the equipment can result from a chemical hazard. Improper operation/setup of equipment can result in contaminated water entering the boiler, the drinking water, etc., which may lead to damaging equipment and may be harmful to personnel.

504-16.6.2 EQUIPMENT MAINTENANCE. For salinity indicating equipment to provide accurate reliable readings, careful and consistent maintenance is essential. Some of the most sensitive parts of a salinity system are the cell electrodes. Salinity cells are submerged in water, which can be a harsh environment (high temperatures, high pressures, and non-conductive suspended contaminants). In this environment, the platinum cell electrodes must be cleaned regularly. Another important part of the maintenance is checking the accuracy of the equipment. If salinity indicating equipment is not providing an accurate measurement, important water systems can be contaminated and possibly damaged.

504-16.6.2.1 Salinity indicating equipment has a set of required preventative maintenance procedures that are part of the Planned Maintenance System (PMS). The PMS for salinity indicating equipment has the following SYSCOM MIP Control Numbers: IC-004, IC-006, and 4371. These procedures are accomplished on a periodic basis, such as quarterly (every three months). The specific periodicity for each procedure is listed below.

504-16.6.2.1.1 The following is a list of the operational maintenance requirements for salinity indicating equipment:

1. Clean, inspect, and test salinity cells. (Quarterly)
2. Test meter, check alarm and dump set points, and test solenoid dump valve operation. (Quarterly of Semi-annually)
3. Clean and inspect salinity panel. (Annually)
4. Calibrate salinity panel. (Annually)

504-16.6.2.1.2 The following are inactive equipment maintenance procedures to be performed during lay-up and start-up periods:

1. Place salinity cells in storage. (Lay-Up)
2. Install protective covers on salinity panels. (Lay-Up)
3. Reinstall salinity cells. (Start-Up)
4. Remove protective covers from salinity panels. (Start-Up)

504-16.6.2.2 Another important part of the maintenance of salinity indicating equipment is the daily chemical comparison tests. The salinity measurement assumes that chloride ions are the only conductive contaminants in water. The chemical comparison test is performed to verify that this assumption is true. This reliable test is performed manually and chemically analyzes the chloride ion concentration of a water sample. This measurement is then compared with the measurement of the salinity indicator to verify there are no conductive contaminants in the water other than chloride ions.

504-16.6.3 CALIBRATION. Commercial salinity indicators (category 4) are covered by NAVSEA's Metrology and Calibration Program. Their calibration cycle is twelve months. For other permanently installed category 1 or 2 salinity indicating equipment, calibration is either performed under the Ships Instrumentation Systems Calibration (SISCAL) Program or the Planned Maintenance System (PMS). Portable salinity indicators are covered under the Navy Metrology and Calibration (METCAL) Program.

## SECTION 17.

## INFRARED THERMAL IMAGING SYSTEMS

### 504-17.1 INTRODUCTION

504-17.1.1 Thermal imaging surveys are routinely conducted by ship and shore based personnel. Although the applications of thermal imaging are almost limitless, they primarily relate to surveys of electrical equipment and heat stress analysis. The information contained in this chapter is an overview of thermal imaging, intended to give the reader basic knowledge. It is not a sole source of training in respect to theory, applications, or equipment operation.

### 504-17.2 ENGINEERING PRINCIPLES

504-17.2.1 The fundamental principle of infrared thermal imaging is based on the fact that every object above Absolute Zero (-273°C or -459°F) will, as a function of temperature, radiate energy along the electromagnetic spectrum. Both the visible light and infrared spectrums are part of the overall electromagnetic spectrum throughout which all energy is radiated (i.e., from gamma rays to radio waves). The visible light energy and infrared energy differ only in their respective wavelengths. Therefore, the operating principles of a thermal imaging system can be compared to an ordinary video camera. Both the thermal imaging system and video camera are passive systems that receive energy radiated at specific wavelengths, i.e., the wavelengths of the visible light spectrum for the video camera and the wavelengths of the infrared spectrum for the thermal imaging system. Also, unlike sonar and radar systems that ″actively″ transmit or emit electromagnetic pulses (or signals) to ″bounce″ off an object, the ″passive″ thermal imaging system only receives energy radiated from an object; thermal imaging systems do not emit an active pulse. The wavelengths of visible light span an approximate range from 0.4 to 0.7 microns whereas the wavelengths of the entire infrared spectrum span an approximate range of from 1.0 to 1000.0 microns. However, with respect to thermal imaging and the instruments (thermal imagers) used to receive/detect the radiated heat energy, we deal with only a small section of the entire infrared spectrum, specifically and typically, the region spanning the wavelengths from 2.0 to 14.0 microns. Note that visible light (0.4 to 0.7 microns) does not extend into the infrared region and subsequently, visible light will not be detected by a thermal imaging system (operating within the 2.0 to 14.0 microns region). Therefore the thermal image of an object will appear the same in a lighted or darkened space.

504-17.2.2 Most objects, including the atmosphere, are opaque (not transparent) to infrared radiation. However, two windows of ″atmospheric transparency″ exist. They are the ranges of 2.0 to 5.6 microns and 8.0 to 14.0 microns. Therefore, manufacturers design their equipment to be responsive within these specific regions.

504-17.2.3 Infrared radiation is emitted from the surface of the object being viewed, detected by the thermal imaging system, and correlated to the object's temperature by converting the radiated energy into electrical impulses having magnitudes directly proportional to the amount of ″heat″ energy received. As the temperature of the object increases, so will the amount of energy it radiates. Therefore, the magnitude of the electrical impulse generated by the thermal imager in the conversion of heat energy to electrical energy will be greater. A comparison of the electrical pulse magnitude readout to those of known temperature references is the method utilized to calibrate the thermal imaging systems. One should also note that except for certain materials, you cannot see through anything using a thermal imaging system; the infrared radiation received by the thermal imager is emitted from the surface of the object being viewed, not from behind or within. Therefore, to view an electrical connection, the enclosure must be opened to obtain a direct line of sight between the object and the thermal imager.

## 504-17.3 DEFINITIONS AND EXPLANATIONS

504-17.3.1 GENERAL. In order to fully understand the operating principles involved with thermal imaging one must understand and be familiar with some terminology. The definitions given below are simplified from the true ″scientific″ definitions in order that the reader may more easily apply them to thermal imaging in shipboard applications.

504-17.3.2 ATMOSPHERIC ATTENUATION. Only when traveling through a vacuum, such as space, will radiation travel unimpeded. The atmosphere absorbs, or attenuates, some or all of the radiation emitted by the object. Atmospheric attenuation is usually ignored for shipboard applications involving distances of less than five (5) meters. Some thermal imaging systems, typically those having temperature measurement capability, have a function that allows for mathematical correction of the atmospheric attenuation.

504-17.3.3 BLACKBODY. An object that is a ″perfect″ radiator of energy is a blackbody, i.e., the object will radiate the theoretical maximum amount of energy corresponding to any given temperature it has stabilized to. A blackbody will be 100% efficient at radiating or emitting energy corresponding to its actual temperature. Aboard ship, no object is perfect or 100% efficient. Therefore, true blackbodies do not exist. The term ″Blackbody″ or ″Blackbody Calibration Source or Standard″ describes sources having emissivity values in excess of 0.9999 (99.99% ″efficient″).

504-17.3.4 COLORED BODY. A colored, selective, or spectral body is an object that is not a ″perfect″ radiator, i.e., the object is not a blackbody. The colored body will be less than 100% efficient at radiating, or emitting, energy corresponding to its true and actual temperature. However, its ″efficiency″ at radiating energy is dependent on the wavelength of the radiated energy. Since the wavelength is a function of temperature, the emissivity of a colored body, or its ″efficiency″ at radiating its true and actual temperature, varies and changes as temperature changes. Thermal imaging and temperature measurements of colored bodies are difficult and require special expertise. For current electrical and heat stress shipboard applications, we do not deal with colored bodies.

504-17.3.5 CRT. Cathode Ray Tube; TV-like screen on which the thermal image is viewed.

504-17.3.6 EMISSIVITY. Emissivity is the ratio of the radiant exitance, or radiance, of a given body to that of a blackbody. In general terms, it is a measure of how efficient the object is at radiating, or emitting, energy as compared to a blackbody (which is perfect or 100% efficient) at the same temperature. Every shipboard object is a gray body with an emissivity of less than 1.0 and is less than 100% efficient at radiating its actual temperature. Thermal imaging systems that have temperature measurement capabilities usually have a function to mathematically correct the temperature readout for the variance in emissivity. The accepted emissivity value to use for electrical surveys is 0.8.

504-17.3.7 GRAY BODY. A gray body is an object that is not a ″perfect″ radiator, i.e., the object is not a blackbody. The gray body will be less than 100% efficient at radiating, or emitting, energy corresponding to its true and actual temperature. However, unlike a colored body, its emissivity, or ″efficiency″ at radiating energy corresponding to its true and actual temperature, is independent of wavelength. The gray body's emissivity, or ″efficiency″ at radiating its true and actual temperature is a constant regardless of wavelength. For shipboard thermal imaging surveys all objects are considered gray bodies.

504-17.3.8 IMAGING RADIOMETER. While all thermal imaging systems present a thermal image on a CRT/ LCD video screen, not all thermal imaging systems have temperature measurement capabilities. An Imaging Radiometer will display a thermal image and has temperature measurement capabilities.

504-17.3.9 INCIDENT RADIATION. Radiated energy from one object that ″strikes″ another object is considered incident radiation. The radiated energy from an object that ″strikes″ the detector element of the thermal imaging system is incident radiation to that detector.

504-17.3.10 LCD. Liquid Crystal Display; TV-like screen on which the thermal image is viewed.

504-17.3.11 LONG WAVE SYSTEM. A thermal imaging system or radiometer designed to operate specifically in the ″long″ wavelength section of the 8.0 to 14.0 micron region of the infrared spectrum. The 8.0 to 14.0 micron region is commonly referred to as the long wave ″window″.

504-17.3.12 RADIOMETER. A radiometer, or spot radiometer (often referred to as a ″heat gun″), is a radiation (heat energy) measuring instrument used for non-contact temperature measurement of an object. The output of a radiometer is a digital display of the radiated temperature of the object at which it was aimed. Spot radiometers do not display a thermal image of the object.

504-17.3.13 SHORT WAVE SYSTEM. A thermal imaging system or radiometer designed to operate specifically in the 2.0 to 5.6 micron region of the infrared spectrum that is commonly referred to as the short wave ″window″.

504-17.3.14 TEMPERATURE SCALE. Degrees Centigrade, or Celsius, is the recommended scale for reporting thermal imaging results; it is the required scale for reporting electrical survey results.

504-17.3.15 THERMAL ANOMALY. An indication, typically a ″hot″ or ″cold″ spot in a thermal image that after evaluation is determined as being outside of normal operating conditions.

504-17.3.16 TOTAL POWER LAW. When energy is incident upon a body/object, some of the energy can be transmitted through the object, some of it can be absorbed by the object, and some of it can be reflected. The values of the three components, transmission (t), absorption (a), and reflection (r), must add up to unity, $t + a + r = 1.0$. For shipboard applications, an object's emissivity (e) is equal to its absorption, therefore emissivity can be substituted into the total power formula in place of absorption. Most objects are not transparent to infrared radiation so for shipboard applications, the transmission (t) component of the formula is zero, leaving only the object's emissivity (absorption) and reflectivity to equal unity, $e + r = 1.0$. Knowing that emissivity plus reflectivity is equal to 1.0 is a key element in understanding thermal imaging.

## 504-17.4 SAFETY

504-17.4.1 GENERAL SAFETY PRECAUTIONS. All personnel and Forces Afloat shall comply with Navy Safety Precautions for Forces Afloat, OPNAVINST 5100 series.

504-17.4.2 ELECTICAL SAFETY PRECAUTIONS. In order to accomplish a thermal imaging survey, the equipment to be analyzed must be on-line and there must be direct line of sight to the component(s) to be analyzed. In order that the direct line of sight requirement be met, the covers and/or doors of electrical enclosures must be opened while the equipment is on-line. Since thermal imaging is a non-contact technique, under no circumstance shall the plane of the enclosure be broken. While enclosures are opened, the immediate area should be secured to prevent inadvertent passage of personnel in the area.

504-17.4.3 THERMAL IMAGING EQUIPMENT PRECAUTIONS. While all thermal imaging systems differ in configuration, they all require that the operator view the thermal image on a CRT/LCD screen or through a monocular viewfinder. Since this requires that the operator's attention be focused on the thermal image, the operator shall never walk about while viewing the screen. Viewing shall only be accomplished while the operator is in a steady and stable position. The field of view presented in the thermal image varies from system to system and objects viewed in the thermal image may be closer than they appear. Therefore the operator shall never reach out or point to an object while viewing the thermal image. Many thermal imaging systems require a number of cables for interconnecting the various components of the system. In order that the cables not be snagged, the operator shall exercise extreme caution while moving about the various spaces.

504-17.4.3.1 Although most newer thermal imaging systems contain integral cooling units or require no cooling, some systems do require the addition of cryogenic liquids or compressed gases. If the thermal imaging system to be used requires the use of cryogenic liquids (i.e., liquid nitrogen) or compressed gases (i.e., argon cylinders), the operator shall follow all applicable OPNAV safety precautions for the cryogenic liquid.

504-17.4.3.2 Some spot radiometers have pointing lasers installed as an integral part of the system. These lasers are used as an aid for locating the exact position of the measurement spot. The laser beam shall never be aimed at another person and the operator shall exercise extreme caution that the laser beam not be reflected off an object and onto/at another person.

## 504-17.5 DESCRIPTION

504-17.5.1 Whether the system is a ″short″ wave or ″long″ wave system, all thermal imaging systems and radiometers consists of at least three essential components:

1. Optics, transparent to specific infrared wavelengths, that collect the infrared radiation and focus it onto the infrared detector. The optics also determine the field of view of the thermal image, i.e., from wide angle to telephoto lenses.
2. A detector that converts the infrared radiation to an electrical signal with a magnitude proportional to the amount of energy received.
3. Electronics that process the signal and display the resulting thermal image or temperature measurement.

504-17.5.2 The spot radiometers, or ″heat guns″ as they are often referred to, are typically a one piece instrument resembling a large, awkward flare gun. Since these instruments produce only a temperature measurement display (not a thermal image) precision aiming at the target is essential. Depending on the manufacturer and model, they are designed with some type of aiming device such as:

a. Single laser beam whereby the laser beam is targeted onto the object. The single laser ″dot″ indicates the center of the measurement spot but gives no indication as to the size of the spot.

b. Dual angled laser beams whereby the position of the two laser ″dots″ indicates the location and diameter of the measurement spot.

c. A rifle type scope with crosshairs where the crosshairs indicate the center of the measurement spot but do not give an indication as to the size of the spot.

d. A viewfinder with a circular reticule whereby the center of the circle is the center of the measurement spot. The circle does not give any indication as to the size of the spot.

e. Rifle type sights used to aim the radiometer as a gun would be aimed. Alignment of the sights indicates the center of the measurement spot and no indication is given as to the size of the spot.

504-17.5.2.1 All spot radiometers make temperature measurements of a spot. The temperature readout indicated is an average temperature of all temperatures within the ″projected″ spot. The spot size (diameter) increases with distance but does not get smaller than the manufacturer's indicated minimum spot size. For example, a typical 30:1 distance to spot size ratio will give a 1″ spot at 30″, a 2″ spot at 60″, but at distances of less than 30″, the spot size will not be reduced proportionally. Positioning and spot size is critical to accurate and meaningful temperature measurements when using a spot radiometer.

504-17.5.3 Thermal Imaging Systems are available in numerous configurations. The systems may require cryogenic liquids or pressurized gases for cooling. They may be internally cooled, or may not require any means of cooling.

504-17.5.4 MIL-I-24698(SH) describes two basic thermal imaging system configurations, Type ″A″ and Type ″B″ systems. Neither system requires the addition of cryogenic liquids or pressurized gases. The type ″A″ system, once assembled (i.e., battery pack and viewfinder attached) for operation, is basically a one-piece system while the type ″B″ system is a multi-component system with interconnecting cables. The type ″A″ system may or may not be radiometric (having temperature measurement capabilities); the type ″B″ system is required to be radiometric, i.e., an imaging radiometer.

504-17.5.5 The infrared detectors of many thermal imaging systems in use today are single detectors with one or more elements used to produce the thermal image. Although infrared radiation from the entire scene or field of view passes through the lens, only a very small part is focused onto the detector at any instant in time. The image is actually produced pixel (picture element) by pixel via the scanning mechanisms within the scanner assembly of the system. The entire process of completing one scan across/through the entire field of view is typically a matter of forty (40) milliseconds or less. The thermal images are generally updated and displayed at rates of 25 or greater frames (images) per second.

504-17.5.6 The newest systems available and in use today are the Focal Plane Array (FPA), or ″staring array″ systems. These systems are somewhat unique in that they require no scanning mechanisms. The detectors are comprised of in excess of fifty thousand detector elements that each individually ″stares at″ and receives the infrared radiation being emitted from only a very small section of the scene within the field of view. The X-Y coordinate of each element on the detector corresponds to the same X-Y coordinate of a pixel in the thermal image. With no scan mechanism, each element generates the thermal information for only one pixel. The elimination of a scanning mechanism not only reduces the power consumption of the system but also enables the system to be designed and built smaller and lighter.

504-17.5.7 Another common system, although not new, that has no internal scanning mechanism is the pyroelectric vidicon system. One such system is the Naval Firefighters Thermal Imager (NFTI). This type of system produces the electrical ″impulses″ and subsequent thermal image only when the vidicon tube senses a change in infrared radiation. If the scanner is held stationary while viewing a non-changing scene, the thermal image will fade away. In order that the vidicon tube senses a change in radiation, the scanner must be constantly moved about to produce the thermal image. Some vidicon systems incorporate a ″chopper″ motor that constantly passes a ″flag″ across the vidicon to produce a ″now you see it, now you don't″ sensation at the vidicon tube; this in effect produces the change in radiation that the vidicon tube requires. The NFTI was designed for firefighter applications and is a damage control item; it is not generally used for thermal imaging of electrical systems.

## 504-17.6 OPERATION

504-17.6.1 Due to the many different thermal imaging systems and spot radiometers currently in use throughout the fleet and the rapidly expanding number of models being made available, it is impossible to detail the operation of each one in this writing. It is the responsibility of the user to learn the details of operation described in each manufacturer's operating or technical manual. The discussion below will describe operational considerations in a generic manner.

504-17.6.2 Whether using a thermal imaging system or spot radiometer, the basic principle is that the object (and finite points/areas of the object) is radiating energy at a level proportional to its temperature. The radiated energy travels through the surrounding ambient air and passes through the ″very transparent″ lens of the thermal imaging system. The radiation is then directed, via ″highly reflective″ infrared mirrors, to the ″highly energy absorptive″ detector. The values of transmission through the lens, reflectivity of the mirrors, and absorption value of the detector are known values and are taken into account in the design and calibration of the system.

504-17.6.3 The detector converts the absorbed radiation into an electrical signal where it is then fed to a signal processor, amplified, and further processed to be displayed as information, i.e., a thermal image and/or a temperature measurement readout on the thermal imager or spot radiometer. The image, or temperature readout, is constantly updated. The thermal imagers and spot radiometers used for shipboard applications are referred to as ″real time″ systems, meaning the viewed image or measurement is constantly updated and appears as a live image on the viewing screen.

504-17.6.4 The object radiating the infrared energy is not a blackbody, therefore, it is not a perfect radiator. The object is a gray body and it is not 100% efficient at radiating the energy corresponding to its true surface temperature. For discussion, we will say that the gray body object is only 80% efficient at radiating the energy associated with its true surface temperature, i.e., its emissivity is 0.80. Applying the Total Power Law, the summation of the three components (emissivity, reflection, and transmission) must equal to 1.0. Since for shipboard applications objects are considered opaque, the transmission component is zero. Therefore, the object's values of emissivity plus reflectivity must equal 1.0.

504-17.6.5 If the object has an emissivity of 0.8 and is assumed to be 80% efficient at radiating energy corresponding to its true and actual temperature, then it follows that the object has a reflectivity of 0.2 and is 20% efficient at reflecting infrared radiation incident upon it. The incident radiation will be from the surrounding ambient as well as surrounding objects (either hotter or colder than the object being observed). Most radiometric measurement systems have a function for specifying an object's emissivity (and by default, the reflectivity) as well as a sensor for detecting the ambient temperature. The internal processor will then quantitatively correct, based on the emissivity value and reflected ambient temperature, the temperature measurement value of the object displayed or focused on.

504-17.6.6 Obviously, input of a correction value into the thermal imager or spot radiometer does not change the actual emissivity, or reflectivity, value associated with the object. While the object remains 80% efficient at radiating its true and actual temperature, it also remains 20% efficient at reflecting surrounding temperatures. For example, if a hot steam line is nearby the object, the infrared radiation emitted by that steam line can reflect off the object, or part of the object, and subsequently be received by the thermal imager where it will appear as a ″hot spot″ on the object.

504-17.6.7 When dealing with reflections and reflected temperatures, the angle of incidence is equal to the angle of reflection. In the example above, the angle at which the radiation from the steam line strikes the object is equal to the angle at which the reflected radiation leaves the object. If the thermal imager is at the coinciding angle (i.e., in line with the reflected energy from the steam line) to the object, a ″hot spot″ will appear on the thermal image of the object. If the angle between the thermal imager changes, the ″hot spot″ will move, disappear, or change. This is an important consideration when determining whether a ″hot spot″ is a true hot spot or a reflected hot spot. One should remember that when conducting thermal imaging, all objects should be viewed (imaged), or measured, from at least two angles to determine whether the thermal image, or radiation received by the thermal imager or spot radiometer, is true or contains reflections. ″True″ hot spots in thermal images do not move, disappear, or change as the angle of viewing changes.

504-17.6.8 Some systems also have a function to correct for the distance between the object and the thermal imager or spot radiometer. For most shipboard applications, the distance factor is not considered significant because readings are usually made at less than five (5) meters. For longer distances, and for knowledge in general, the atmosphere or surrounding ambient air, will attenuate or absorb some of the infrared radiation being emitted by the object. Even though the atmosphere has two ″windows″, short wave (2.0 to 5.6 microns) and long wave (8.0 to 14.0 microns), these windows are not 100% transparent to the infrared radiation. In short, the quantity of energy that leaves the object is not the quantity that ″arrives″ at the thermal imager, some of it is lost or absorbed by the atmosphere or surrounding ambient air.

504-17.6.9 As discussed, an object's emissivity (and by default, its reflectivity) and the distance between the object and thermal imager are important factors to consider when analyzing the thermal image of an object and/or making temperature measurements. When making temperature measurements with a spot radiometer (heat gun), the distance factor is not only important, it is critical because of the change in spot size with distance.

504-17.6.10 Once a thermal image has been analyzed and determined to have a thermal anomaly (or problem), a quantitative temperature measurement is required to determine the severity of the problem. For shipboard thermal imaging surveys of electrical systems, the emissivity of the components is considered to be 0.8 and temperature measurements are made as differential temperature measurements. That is, the temperature of the thermal anomaly is given as a temperature rise above a normal operating component/reference or in some cases, as a temperature rise above ambient. Choosing the proper reference is taught during all thermal imaging training courses. The reason temperature is reported as a temperature rise, not the actual temperature, is two-fold: (a) measuring actual and true temperatures requires higher skill levels than measuring the temperature, differentials and (b) unless a baseline is established which includes all the environmental, operational, and thermographic parameters and variables, and provisions are made for adjustments to the variables, the actual temperature of a component is less meaningful than the comparison of temperatures between the thermal anomaly and a normally operating reference component. In order that these temperatures rises most accurately reflect the true temperature differential and severity between normal and abnormal operating conditions, the equipment should be allowed to thermally stabilize. An on-line period of approximately 30 minutes will allow for thermal stabilization. If operational requirements preclude the 30 minute stabilization period, all data and temperature measurements taken should include an annotation reflecting the shortened on-line operating cycle and an indication that the temperature rise will be higher with extended operation.

504-17.6.11 The results of all electrical surveys shall be reported as temperature rises in degrees Celsius/Centigrade (°C). If requested, the results may include the addition of the Fahrenheit temperature conversion in parenthesis following the °C temperature rise (example Temperature rise of 20°C (68°F)). Results are not to be reported as ″stand alone″ Fahrenheit temperatures. Temperature measurements made during surveys of electrical systems are reported as temperature rises (in °C) and assigned repair priorities and severity codes as noted in Table 504-17-1.

**Table 504-17-1.** ELECTRICAL INSPECTION CRITERIA

| TEMPERATURE RISE | REPAIR PRIORITY | SEVERITY CODE | REMARKS |
|---|---|---|---|
| 70°C and above | Immediate | **** | Component failure imminent, repair immediately. |
| 40°C to 69°C | Mandatory | *** | Component failure almost certain unless corrective action taken. |
| 25°C to 39°C | Important | ** | Component failure probable unless corrective action taken. |
| 1°C to 24°C | Desirable | * | Component failure improbable but corrective action required at next maintenance period or as scheudling permits. |

The temperature rises listed above indicate the measured temperature differential (rise) between the abnormal connection (or component) and a reference (normal) connection/component or between the connection/component and ambient temperature. The above criteria are based on the former Military Standard MIL-STD-2194(SH).

## 504-17.7 CARE AND MAINTENANCE

504-17.7.1 In general, the equipment should be handled with extreme care. If a thermal imaging system or spot radiometer is damaged, it will most likely need to be returned to the manufacturer for repair. Other than fuse replacements, the preventive maintenance required is indicated below.

504-17.7.2 The lenses of the thermal imaging systems have special coatings that if scratched will degrade the operating performance of the system. Therefore, the protective lens cap should always be in place when the system is not in the operational mode, i.e., during storage and during movement about the ship. If a lens should become dirty, it can be cleaned by first ″blowing″ off any loose dirt/grit and then gently wiping the surface with cotton balls moistened with lens cleaning fluid, water, or isopropyl alcohol (refer to the manufacturer's operating/technical manual for specific instructions). Each cotton ball should be used for only ″one swipe″ of the lens so as not to grind/rub in any particles remaining on the lens surface.

504-17.7.3 Most spot radiometers have a protective, infrared transparent dust shield installed at the aperture of the unit to prevent dust infiltration. Care should be exercised to protect the shield just as one would protect the lens of a thermal imaging system. However, the dust shield is user replaceable if damaged. These units are normally supplied with replacement shields and instructions for replacement are provided in the manufacturer's technical manual.

504-17.7.4 On multi-component thermal imaging systems, cables/connectors should be inspected for damage each time the system is readied for use; do not energized a system if any cable or connector is damaged. Although one must move about cautiously when carrying a thermal imaging system or spot radiometer, extreme care should be exercised to avoid snagging the cables when moving about the ship using the multi-component systems.

### 504-17.8 CALIBRATION

504-17.8.1 The calibration standards and controlled environments required to calibrate the radiometric (temperature measurement) thermal imaging systems and spot radiometers are not available aboard ship. Therefore, at the expiration of the calibration interval as detailed in paragraph 504-1.2, all equipment requiring calibration must be submitted to an approved Type III calibration facility.

504-17.8.2 If the calibration of a radiometric unit is suspect at any time during the calibration interval, a Field Accuracy Check should be performed. The Field Accuracy Check will verify the existing low temperature measurement characteristics in the range of 0°C to 100°C and is accomplished by making temperature measurements of two readily available temperature sources. This procedure is outlined in the **Submarine Engineering Management, Monitoring, and Fleet Support (SMMS) Program Office Thermal Imaging Guide Book** , 9504.4-SMMS-GYD, Revision B, dated February 1995 and discussed in paragraph 504-17.8.3.

504-17.8.3 Whether using a radiometric thermal imaging system or spot radiometer, take temperature measurements of a melting ice cube (≅ 0.0°C) and a pot of rapidly boiling water (≅ 100.0°C). If the pot is stainless steel, rather than Pyrex glass, a piece of black electrical tape must be affixed (because of emissivity changes) prior to bringing the water to a boil. Temperature measurements are made after setting the emissivity value of the radiometric instrument to 0.95. If using a spot radiometer, be certain to consider the target distance and the spot size being measured. Although the measurement points of 0.0°C and 100°C will give a valid indication of measurement accuracy in the lower temperature ranges, it will not replace the scheduled periodic calibration.

## SECTION 18.

## HYDROGEN SULFIDE ($H_2S$) GAS DETECTORS

### 504-18.1 ENGINEERING PRINCIPLES

504-18.1.1 EQUIPMENT USE. All Naval vessels are equipped with a sanitary collection holding and transfer system. During storage, Hydrogen Sulfide ($H_2S$) gas is generated through bacterial decomposition of raw sewage. $H_2S$ gas detection systems monitor the air in the sanitary waste system equipment space giving both audible and visual warnings of hazardous levels of $H_2S$ gas.

504-18.1.2 EQUIPMENT THEORY. There are two types of $H_2S$ gas detectors, permanently mounted (stationary) and portable. The operation for gas analyzers starts with an electrochemical sensor assembly that produces a change when exposed to $H_2S$. This change is processed and converted to electrical signals that are processed by a central unit. When the detector signal reaches a value that corresponds to 10 PPM of $H_2S$, the central unit's **Warning** alarm indicators energize. When the signal reaches a value that corresponds to 50 PPM $H_2S$, the **Danger** alarm indicators energize. Portable $H_2S$ monitors utilize a single sensor and are completely contained in a single package intended for infrequent use. The stationary types continually monitor multiple sensors, provide multiple warning outputs and are packaged in several components.

### DEFINITIONS

504-18.2.1 AMBIENT AIR. Ambient air is the atmosphere we breathe composed of nitrogen, oxygen and carbon dioxide.

504-18.2.2 CALIBRATION GAS. A gas mixture with a known concentration of $H_2 S$ in nitrogen used to set a monitor's span or alarm level. The concentration of the $H_2 S$ gas is measured in parts per million.

504-18.2.3 CONTROL UNIT. The control unit is the portion of the detection system that processes the electrical signals obtained from one or more detector heads. When preset thresholds are exceeded, the unit produces an alarm indication.

504-18.2.4 DANGER ALARM CONDITION. A condition when one or more of the detector heads detect $H_2 S$ concentrations above 50 parts per million (PPM). Stationary $H_2 S$ gas detectors indicate a **Danger** alarm condition with red lights and bells.

504-18.2.5 DIFFUSION. Diffusion is a process by which the atmosphere being monitored is transported to the gas-sensing element by natural random molecular movement.

504-18.2.6 GAS-SENSING ELEMENT (SENSOR). The gas sensing element is a subassembly in a detection instrument that, in the presence of a specific gas, produces a change in its electrical, chemical, or physical characteristics.

504-18.2.7 HYDROGEN SULFIDE ($H_2 S$). The gas sensing element is a subassembly in a detection instrument that, in the presence of a specific gas, produces a change in its electrical, chemical, or physical characteristics.

504-18.2.8 PARTS PER MILLION (PPM). Parts per million is a relative term used to define the concentration of one gas within another.

504-18.2.9 PORTABLE. Portable refers to a self-contained and battery operated instrument that is not permanently installed.

504-18.2.10 RANGE. Range is a series of values representing specific concentrations of $H_2 S$.

504-18.2.11 SPAN. Span is the algebraic difference between the upper and lower values of a range.

504-18.2.12 STATIONARY. Stationary refers to an instrument permanently installed in a fixed location.

504-18.2.13 WARNING ALARM CONDITION. A condition when one or more of the detector heads detect $H_2 S$ concentrations above 10 parts per million (PPM). Stationary $H_2 S$ gas detectors indicate a **Warning** alarm condition with yellow lights and buzzers.

## 504-18.3 SAFETY

504-18.3.1 $H_2 S$ SAFETY INFORMATION. Hydrogen Sulfide ($H_2 S$) is a rapid acting systematic poison that causes respiratory paralysis with subsequent asphyxia at high concentrations. $H_2 S$ gas can enter the body through the lungs, skin, or eyes. Even low concentrations of $H^2 S$ can be dangerous.

Exposure at 20 PPM causes irritation of the eyes and throat

Deadening of the sense of smell occurs between 50 PPM and 100 PPM

Headaches, dizziness, and fatigue result from exposure to levels of 250 PPM

Unconsciousness takes place rapidly at levels of 500 PPM. A single breath of 600 to 800 PPM can cause unconsciousness quickly followed by coma and death.

Existing medical conditions are aggravated by exposure to $H_2$ S.

504-18.3.1.1 If inside a monitored space, upon observing a **Warning** or **Danger** condition alarm, LEAVE THE SPACE IMMEDIATELY. Use an Emergency Escape Breathing Device (EEBD) when escape is delayed. If outside a monitored space and a **Warning** or **Danger** condition alarm is sounding, DO NOT ENTER THE SPACE. In either case report the condition to the DCA immediately. It must be assumed that a dangerous level of $H_2$ S exists in the space even if only one detector head is indicating a **Warning** condition. Some detector heads will sense the levels of $H_2$ S before others depending on their location relative to the source of the $H_2$ S leak.

504-18.3.1.2 The ability to reset the system and clear the alarm cannot be relied upon as an indication the space is safe for entry. Any alarm condition in a sanitary waste system equipment space must be investigated, corrected and the space certified gas free by the ship's Gas Free Engineer.

504-18.3.2 ELECTRICAL SAFETY PRECAUTIONS. The stationary $H_2$ S gas detection system is powered by 115 VAC fed from multiple sources. Do not perform internal equipment maintenance without first removing all sources of electrical power. Under no circumstances should any person service or troubleshoot the equipment except in the presence of someone who is capable of rendering aid.

504-18.3.3 CALIBRATION MODE SAFETY PRECAUTIONS. The stationary $H_2$ S gas detector system will not activate any alarms when it is in the calibration mode. Do not leave the system unattended when it is in the calibration mode. Under no circumstances should any person put the system in the calibration mode except in the presence of someone who is capable of rendering aid in an emergency. When the system is put in the calibration mode, it will return to the normal mode after 30 minutes if no $H_2$ S is sensed by a detector. However, since the purpose of the calibration mode is to flow the calibration gas, containing 10 PPM of $H_2$ S, across the detectors to ensure the unit's correct operation, the gas detector system will not return to normal mode. Always return the system to normal operation mode by pressing and holding the **Reset** button for at least one second before leaving the area.

504-18.3.4 CALIBRATION TEST GAS CYLINDER STORAGE AND HANDLING. Store the gas cylinder as specified in OPNAVINST 5100.18B, ″Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,″ Volume II, Section C2309. Do not expose the cylinder to excessive heat. Excessive heat may cause the cylinder to explode. Store in well-ventilated areas only. Keep cylinder valves closed at all times when not in use. Secure gas cylinders to prevent them from falling. Always store the cylinder in a place that will protect it from physical damage. If the cylinder leaks, ventilate the area and prevent the escape of gas if possible. Remove the gas cylinder to a safe outdoor location and allow to discharge at a slow rate. Dispose of depleted cylinders in accordance with established procedures.

## 504-18.4 DESCRIPTION

504-18.4.1 STATIONARY $H_2$ S GAS DETECTION SYSTEM. Figure 504-18-1 shows a typical permanently mounted Sierra Monitor Corporation (SMC) Model 1400 $H_2$ S gas detection system which consists of a control unit, four gas detector heads, and external warning alarms. The system has a detection range of 0 to 100 PPM

$H_2$ S. In the sanitary waste system equipment space, three of the detector heads are located near the system pumps and valves. The other detector is usually located near the space's exhaust ventilation duct opening. The control unit is located on the bulkhead just outside of the entrance to the space.

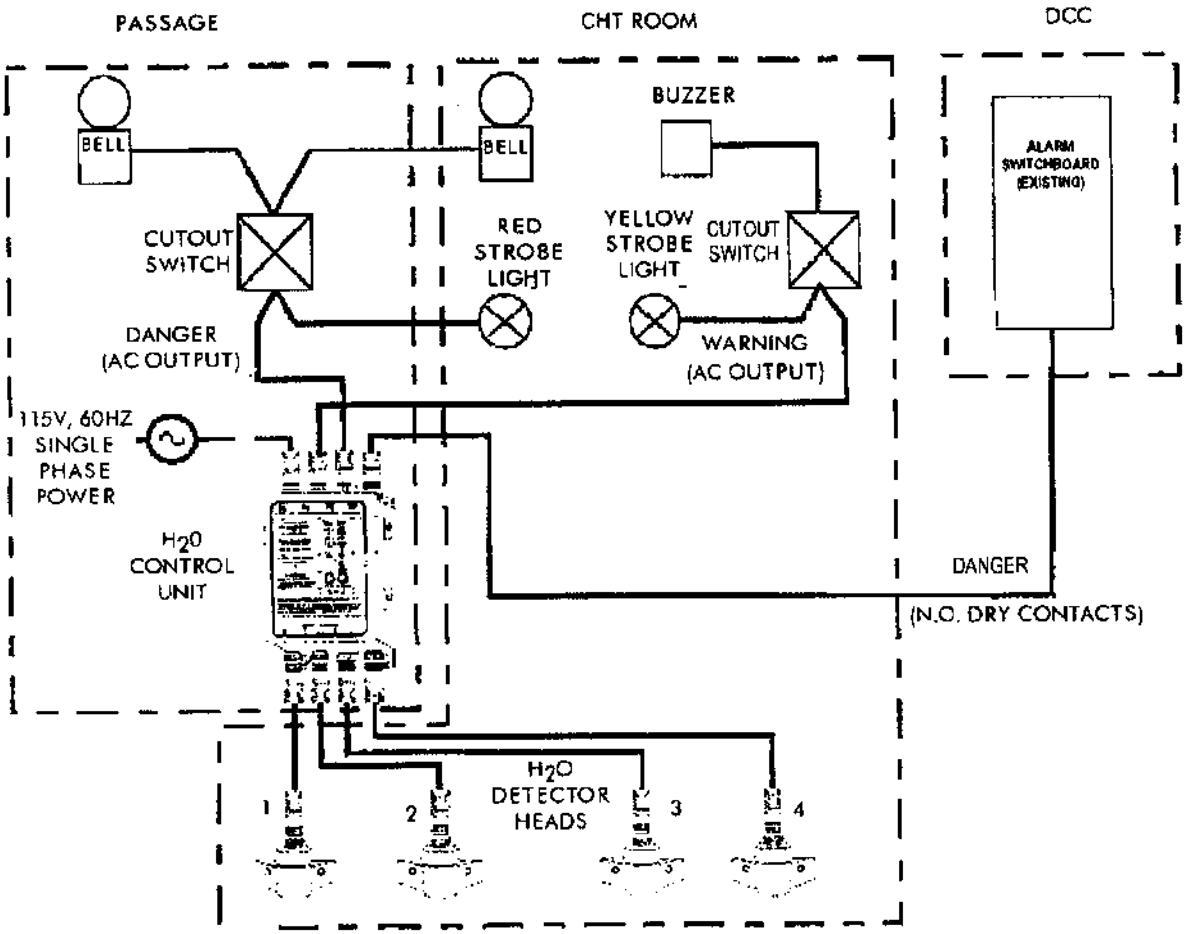



Figure 504-18-1. $H_2$ S Detector System

504-18.4.1.1 Control Unit. The control unit is a stainless steel enclosure that houses the circuitry that controls the system. See Figure 504–18–2. The front panel of the control unit enclosure has a **Reset** and a **Calibrate** push-button which are used to put the system in various operating modes. The front panel also has two green LEDs for **Power** available and **Safe** condition operation, two yellow LEDs for a **Warning** alarm condition and **Failure** indication, and a red LED for a **Danger** alarm condition. The control unit front panel also has four light green LEDs to indicate which detector head(s) are currently sensing $H_2$ S in the case of an alarm, or no longer operating in the case of a **Fail** indication. On the enclosure are connectors for AC power, external alarm cabling and detector head cabling.

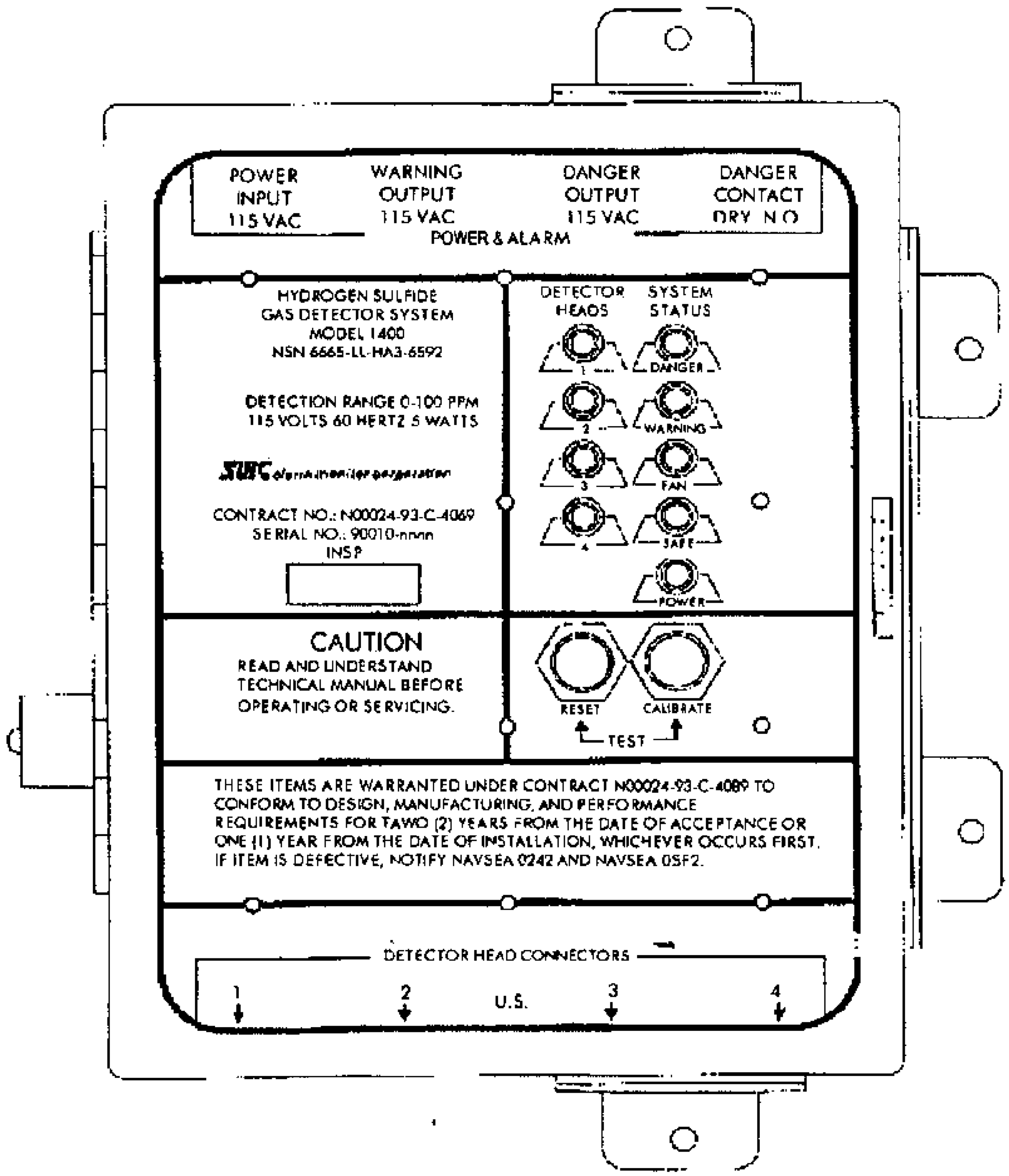



Figure 504-18-2. Control Unit Face Plate

504-18.4.1.2 Detector Heads. Each of the four detector heads includes a replaceable sensor assembly and a fully encapsulated electronic transmitter assembly within a stainless steel housing. The transmitter is connected to the control unit with a twisted pair cable.

504-18.4.1.3 External Alarms. The external alarms consist of buzzers, bells, and red and yellow strobe lights to warn personnel of potentially dangerous levels of $H_2S$ within the monitored space. The buzzers, bells and strobe lights are located on the control unit and inside the sanitary waste system equipment space. On ships with two entrances to the sanitary waste system equipment space, a bell and two indicator lights are located outside the secondary entrance. On most shipboard systems, the control unit is also connected to an Interior Communications Summary (ICSM) alarm panel located in Damage Control Central (DCC).

504-18.4.1.4 Calibration Kit. The calibration kit consists of a certified cylinder of 10 PPM $H_2S$ in nitrogen test gas, a pressure regulator, a calibration fitting that connects to the detector head, a short length of Teflon tubing that connects the regulator to the calibration fitting, and a carrying case. See Figure 504–18–3.

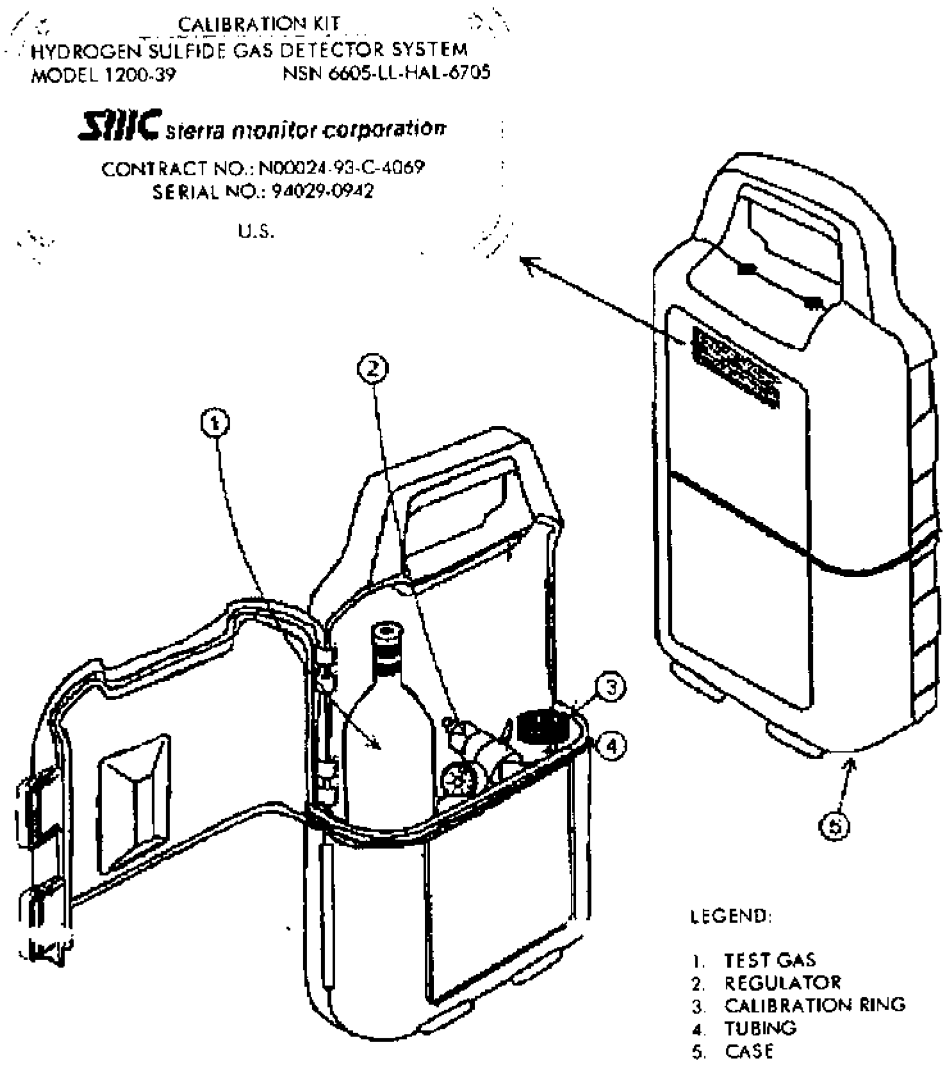



Figure 504-18-3. Calibration Kit

504-18.4.2 PORTABLE $H_2$ S GAS DETECTORS. Portable $H_2$ S gas detectors come in a variety of types. In general, the sensing element, audible alarm, visual alarm, and self test button are contained in one enclosure. Some portable units also have a digital display for the level of $H_2$ S in PPM. Portable $H_2$ S gas detectors are powered by a battery, usually a standard 9-volt type. The sensing ranges of portable $H_2$ S gas detectors can be as high as 1000 PPM. Most portable units have two alarms that can be adjusted from inside the control unit. The first alarm should always be set at 10 PPM $H_2$ S and the second should always be set at 50 PPM $H_2$ S. Detailed descriptions of the features of a portable $H_2$ S gas detector can be found in its instruction manual.

**OPERATION**

504-18.5.1 SMC 1400 STATIONARY $H_2$ S DETECTORS.

504-18.5.1.1 Detector Head Channel Indication. The four green LEDs in the front panel of the control unit correspond to each of the four detector heads and should be off during normal, safe mode operation. If a **Warn-**

**ing** or **Danger** alarm condition exists, the detector head channel LED is on for the detector head(s) sensing high levels of $H_2$ S. If the **Fail** LED is on, a corresponding **Detector Head Channel** LED will also come on to indicate which detector head is no longer monitoring the space for $H_2$ S. It is possible for the**Fail** and **Alarm** condition to exist at the same time, in which case it would not be possible to determine which detector head has failed and which is sensing the $H_2$ S until the cause of the alarm has been corrected and the alarm has been cleared. The detector head channel indicator is also used during the system test, calibration, and mapping procedures.

504-18.5.1.2 Safe Indication. The green **Safe** LED on the front panel of the control unit will be on during normal safe mode operation of the system. During **Warning** or **Danger** alarms, the **Safe** LED will not be illuminated. If a detector head has failed and the **Fail** indicator is on, the **Safe** LED will not be illuminated. The **Safe** LED will also be off during the calibration procedure.

504-18.5.1.3 Warning Alarm Indication. The yellow **Warning** LED will turn on when one or more detector heads senses $H_2$ S levels above 10 PPM. The **Safe** indicator will turn off and the **Detector Head Channel** LED(s) for the detector head(s) sensing the $H_2$ S will illuminate. The buzzer and yellow strobe light in the sanitary waste equipment space will also be activated. The control unit will also turn on the yellow light in the two indicator light fixture located outside the secondary entrance to the space (if the ship is so equipped). The **Warning** alarm set point cannot be adjusted.

504-18.5.1.4 Danger Alarm Indication. The red **Danger** LED will turn on when one or more detector heads senses $H_2$ S levels above 50 PPM. The **Warning** indications described in paragraph 504-18.5.1.3 will continue because the level of $H_2$ S is above 10 PPM. The red strobe light and bell in the sanitary waste equipment space, the bell in the passageway outside the space, and the ICSM alarm in DCC (if the ship is so equipped) will be activated. The control unit will also activate the bell and turn on the red light in the two dial indicator light fixture located outside the secondary entrance to the sanitary waste equipment space (if the ship is so equipped). The **Danger** alarm set point cannot be adjusted.

504-18.5.1.5 Fail Indication. The yellow **Fail** LED in the front panel of the control unit will turn on when the control unit is no longer receiving a 4 to 20 milliamp signal from one or more of the detector heads. The **Fail** indication could be caused by a disconnected or damaged cable between the detector head and the control unit, a detector head that has been flooded or sprayed with too much water, or a sensor assembly that no longer works due to aging.

504-18.5.1.6 Power Indication. When 115 VAC power is supplied to the control unit, the green **Power** LED will be on at all times.

504-18.5.1.7 Reset Button. The **Reset** push-button is located on the front panel of the control unit. It is used to reset the system to the normal operating mode after an alarm condition. The system will not reset as long as $H_2$ S levels above 10 PPM are sensed by one or more detector heads. The **Reset** button is also used during the mapping procedure, calibration procedure, and system test.

504-18.5.1.8 Calibrate Button. The**Calibrate** push-button is located on the front panel of the control unit. It is used to put the system into the calibration mode for system calibration. The **Calibrate** push-button is also used during the system test procedure.

504-18.5.1.9 Warm-up. The $H_2$ S gas detector system will go through a 2-minute warm-up procedure when AC power is connected to the control unit after the system has been turned off. During this procedure, the **Power** LED indicator will be on. The **Fail** indicator will blink (one on/off cycle per second) during the two minute warm-up period. All other LEDs on the control unit will be off. Upon completion of the warm-up procedure, the system will be operating.

504-18.5.1.10 System Test. The system test electronically simulates a **Danger** condition at the control unit and allows the operator to verify that all of the external alarms and LEDs are operating properly. When the **Reset** and **Calibrate** push-buttons are held in for 5 seconds, the simulated **Danger** condition will turn on all external alarms and light all of the control unit front panel LEDs. The system returns to the normal operation mode by pressing the **Reset** button for 1 second.

504-18.5.1.11 Detector Head Mapping. Detector head mapping determines which detector heads are connected and working. The information is stored in the control unit's memory and is not lost when power is removed from the control unit. Detector head mapping is performed when detector heads are installed, removed, or when the number of operating detector heads needs to be determined. Detector head mapping is started by holding the **Reset** button in for ten seconds. During the next 10 seconds, the detector head indicator LEDs on the control unit will go on for all detector heads that are properly connected and working. The **Safe, Fail, Danger,** and **Warning** LEDs on the control unit will be off during this period. After the 10 second mapping process, the system will return to the normal operation mode. Any detector heads that were not mapped (the **Detector Head Channel** LED did not go on during the procedure) will no longer be monitored by the control unit during normal operation. When the detector head connections have been restored, the system will have to be remapped to inform the control unit that those detector heads are reconnected.

504-18.5.2 PORTABLE DETECTORS. The operating procedures and controls for portable $H_2$ S gas detectors vary according to the manufacturer. Read the portable detector's instruction manual for detailed operating procedures.

## 504-18.6 CARE AND MAINTENANCE

### 504-18.6.1 STATIONARY DETECTORS

504-18.6.1.1 Detector Heads. The detector heads are mounted inside the sanitary waste system equipment space. They are typically located near the most likely source of $H_2$ S gas which is the waste system pumps and valves. One detector is usually located near the exhaust ventilation duct. In general, the openings on the bottom of the detector heads are located 2 inches above the coaming that surrounds the CHT pumps and piping. This positioning allows the mounting of detector heads low enough for maximum warning yet prevents the sensors from being damaged if the coaming fills in the event of a leak. Care must be taken to prevent the sensor from getting wet when the space is washed down. The detector heads should never be exposed to direct spray from a water hose. If any water enters the detector head, the sensor is destroyed and must be replaced. The sensing elements are cross sensitive to vapors from other chemicals, especially chlorine and sulfur dioxide. Avoid exposure of the detector heads to these chemicals. The detector heads should never be painted or covered. Paint can block the holes in the bottom of the detector head housing that allow air to reach the sensor assembly. Paint may also contain compounds that could contaminate the sensors. Covers or other protective guards can block the flow of air to the sensor and slow or stop the sensor response time to $H_2$ S. Any material that fills or partially fills any of the holes in the bottom of the detector head housing should be promptly removed.

504-18.6.1.2 Sensor Assembly Replacement. The sensor assembly is located inside the detector head. Sensor assemblies have an expected service life of at least 3 years, however, replacement of the sensor assembly is recommended after 3 years of installed service. Figure 504–18–4 shows the detector head and sensor assembly. To replace the sensor, the cable connector plug is removed from the top of the detector head. The transmitter assembly is then removed by unscrewing the top section of the detector head housing. The old sensor assembly is removed from the transmitter assembly by pulling the sensor assembly straight out. As shown in Figure 504–18–4, new sensor assemblies come prepackaged with a shorting spring across pin R and pin S. The shorting spring should not be removed until the transmitter assembly is ready to receive the new sensor assembly. If the shorting spring is removed and the new sensor is not plugged into the transmitter assembly within five minutes, an electrical charge will build up in the sensor assembly and render the new sensor useless. The new sensor is plugged into the transmitter assembly by lining up the three pins on the sensor and transmitter assemblies and pushing the sensor assembly in. The installation date is recorded on the label on the side of the sensor assembly and in the $H_2$ S gas detector log book. The transmitter assembly is then hand tightened onto the detector head housing and the cable connector reconnected. Once power has been restored to the sensor, the **Detector Head Channel** LED and **Fail** LED on the control unit will blink for two minutes and then shut off. The new sensor has a sensor stabilization time of two hours. Power must be applied to the sensor for two hours before the new sensor can be calibrated. Once the two hour stabilization time has passed, the sensor can be calibrated following the calibration procedure.

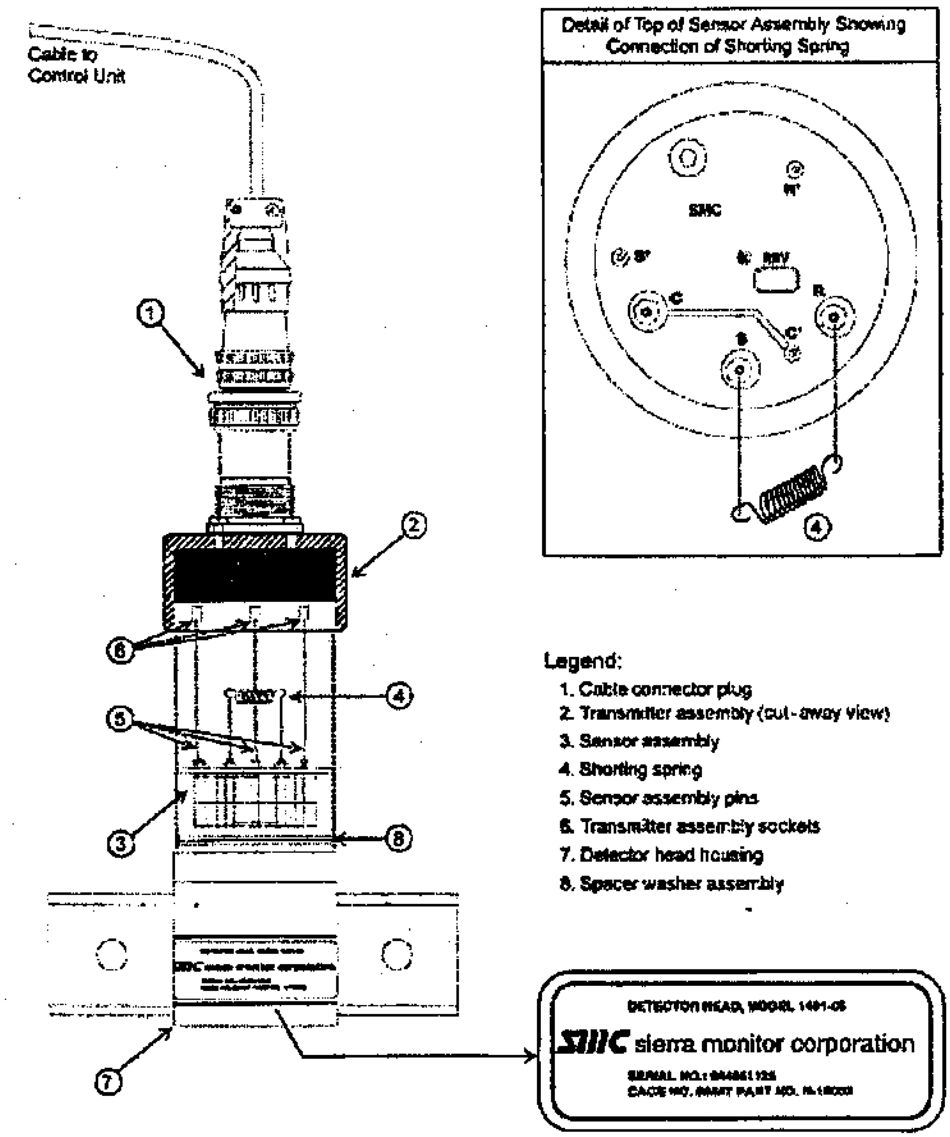



Figure 504-18-4. Detector Head

504-18.6.1.3 Interconnections. The control unit is connected to the detector heads with shielded, twisted pair cables and MS/Standard Cylindrical MIL-C-5015 Connectors, AN Type, style MS3406 Plugs. If the cabling and/or connector is damaged, the technical manual for the system provides detailed procedures for reconnecting the cable to the connector, and replacing the connector assemblies on the control unit. Shielded cable must be used to ensure the electromagnetic interference (EMI) protection of the system.

504-18.6.1.4 Control Unit. The only required regular maintenance required for the control unit is performed during the system test. All other maintenance on the control unit is corrective maintenance. Procedures for any corrective maintenance on the control unit are described in the technical manual for stationary $H_2$ S gas detector systems.

504-18.6.1.5 External Alarms. All of the external alarms are tested during the system test. Any burned out light bulbs should be replaced. Repair any damaged or disconnected bells, buzzers, or cutout switches as required.

504-18.6.2 PORTABLE DETECTORS. The care and maintenance procedures for portable $H_2S$ gas detectors vary according to the manufacturer. Read the portable detector's instruction manual for detailed care and maintenance procedures.

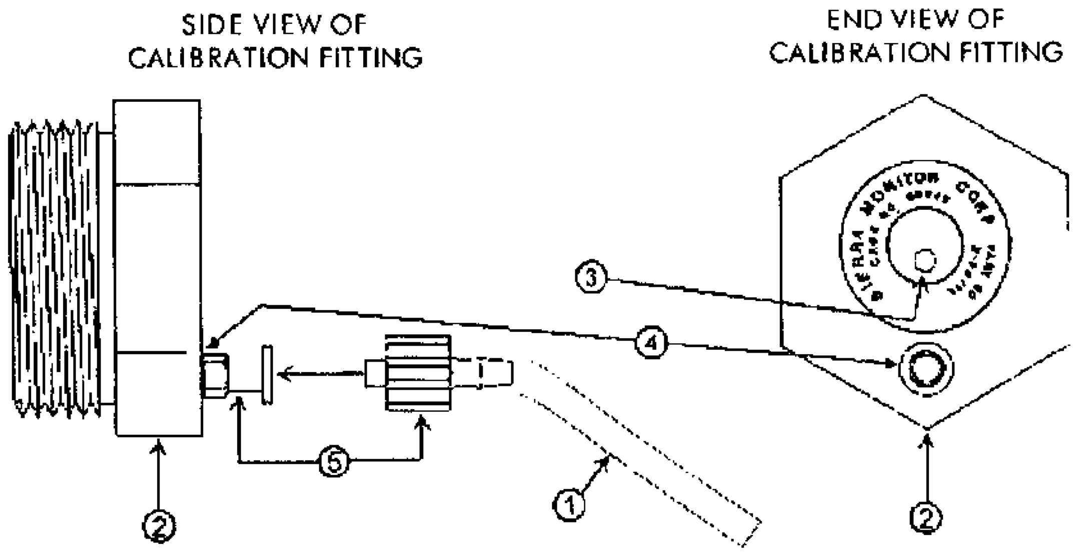
## 504-18.7 CALIBRATION

### 504-18.7.1 STATIONARY DETECTORS

504-18.7.1.1 Calibration Test Gas Shelf Life. The calibration test gas cylinder contains 10 parts per million (PPM) $H_2S$ in nitrogen that has a certified accuracy of ±5%. The calibration test gas has a shelf life of one year. The expiration date of the test gas is stamped on the shipping carton for the gas cylinder.

504-18.7.1.2 Stationary Detectory Calibration Interval. Calibrate the system after initial installation and in accordance with PMS thereafter. The system must also be recalibrated either fully or partially after any maintenance is performed. Calibration of all four detectors is required if the control unit printed circuit board is replaced. A calibration curve is stored in the control unit's memory for each detector. When any detector's component is changed, a new set of calibration curves must be developed. If power is removed from the system, the system does not have to be recalibrated because the control unit memory retains the calibration curves when power is interrupted.

504-18.7.1.3 Calibtation Method. The system is calibrated by applying the $H_2S$ test gas to the detector heads. During detector calibration, a new calibration curve is created and stored in the control unit's memory when 10 PPM of $H_2S$ is applied to the detector head for 5 minutes. The system calibration is started by pressing the **Calibrate** button on the control unit for 5 seconds and putting the system in the calibration mode. If the detector senses ambient $H_2S$ levels above 3 PPM using the old calibration curves, the **Detector Head Channel** LED blinks at a rate of 4 cycles per second and the calibration cannot be performed until the low levels of $H_2S$ have been removed from the space. After the system is in the calibrate mode, the calibration fitting is screwed into the bottom of the detector head to be calibrated (see Figure 504–18–5 and Figure 504–18–6). The gas regulator is connected to the calibration gas cylinder. The Teflon tube is used to connect the gas regulator output to the calibration fitting. Once all of the connections have been made, the gas cylinder valve and gas regulator valve are opened and the $H_2S$ calibration test gas is applied to the sensor for five minutes. During this five minute interval, the **Detector Head Channel** LED for the detector head that is being calibrated will start to blink once per second if the calibration is proceeding normally. After the five minute interval, the valve on the gas cylinder is closed and the calibration fitting is removed from the detector head. The **Detector Head Channel** LED for the detector head should stop blinking 10 seconds after the calibration fitting is removed. Once the **Detector Head Channel** LED stops blinking, the new calibration curve has been stored in the control unit's memory and the calibration for that sensor is complete. The calibration procedure can then be repeated for the remaining detectors. The date of calibration for each sensor should be noted in the $H_2S$ gas detector log book.




LEGEND:
1. TUBING
2. CALIBRATION FITTING
3. GAS ESCAPE VENT
4. GAS INTAKE FITTING
5. TUBING FITTING SCREWS INTO CALIBRATION FITTING

Figure 4-2. Calibration Fitting and Tubing

**CAUTION**

There is a valve on the top of the gas cylinder and a valve on the regulator. Turn the gas cylinder valve clockwise (CW) to close it and counterclockwise (CCW) to open it. Turn the regulator valve counterclockwise to close it and clockwise to open it.

Figure 504-18-5. Calibration Setup

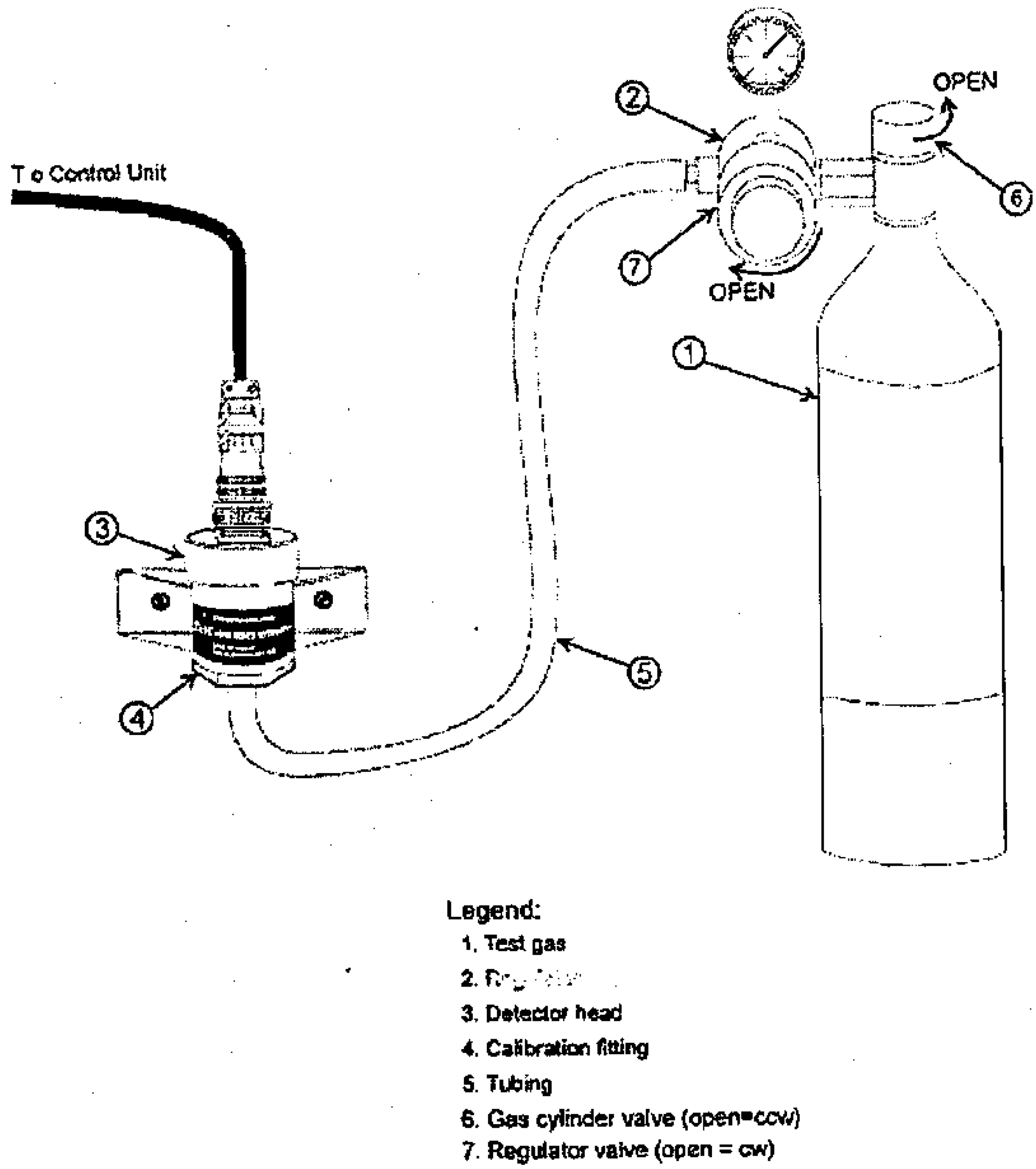



Figure 504-18-6. Calibration Configuration

504-18.7.2 PORTABLE DETECTORS

504-18.7.2.1 Calibration Test Gas. All portable detectors come with a small cylinder of test gas. All $H_2$ S test gas cylinders are a mixture of 10 PPM of $H_2$ S in air or nitrogen.

504-18.7.2.2 Calibration Interval. The calibration interval of portable $H_2$ S gas detectors varies with the manufacturer. All portable detectors require calibration by the user prior to each use, using the manufacturer's calibration kit, in accordance with NAVSEA S6470-AA-SAF-010 for the gas free engineering program.

504-18.7.2.3 Calibration Interval. The method for calibration of portable $H_2$ S gas detectors varies with the manufacturer. In general, first perform a zero adjustment in clean air by turning a potentiometer inside the gas detector. Then adjust the span by connecting a calibration fitting to the detector, exposing it to a known level of $H_2$ S, and adjusting a second potentiometer inside the unit. A log book of calibration dates must be kept for all portable $H_2$ S gas detectors. Some portable $H_2$ S gas detectors have adjustable alarm points. One alarm should be always be set at 10 PPM $H_2$ S.

## REAR SECTION

**NOTE**

TECHNICAL MANUAL DEFICIENCY/EVALUATION EVALUATION REPORT (TMDER) Forms can be found at the bottom of the CD list of books. Click on the TMDER form to display the form.